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PHOSPHORUS REMOVAL BY AN ACTIVATED SLUDGE PLANT

Milwaukee Sewerage Commission

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U.S. ENVIRONMENTAL PROTECTION AGENCY

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PHOSPHORUS REMOVAL BY AN ACTIVATED SLUDGE PLANT

by

Sewerage Commission of the City of Milwaukee
Milwaukee, Wisconsin 53201

for the

ENVIRONMENTAL PROTECTION AGENCY

Program #17010 DXD
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ABSTRACT

The Milwaukee plants removed an average of 80% of the influent total phosphorus (TP). Milwaukee offered an opportunity for plant scale demonstration and study of the activated sludge process parameters effects on TP removal.

The high TP removals were due to sufficient solids production from the amounts of TP, BOD and suspended solids in Milwaukee sewage. Phosphorus balances demonstrated an average of 95.7% of the phosphorus removed was recovered in the waste sludge withdrawn as Milorganite.

An equation was developed for predicting % TP removal from East Plant (EP) 1968 data. Applied to 1969 and 1970 data when TP removals exceeded 80%, the significant parameters were food to microorganisms (F/M), MLSS, and TP to microorganisms (TP/M). The significance of ML-DO, air application rate and detention time could not be shown.

Plant scale studies revealed that F/M, MLSS and TP/M mainly affected soluble orthophosphate (SOP) removal. The removal of SOP was associated with MLSS biological activity by oxygen uptake rate measurements in tank studies. A ML-DO $\geq$ 2.0 mg/L past the tank turnpoint was effective for SOP removal. Insolubilization of SOP by sewage soluble cations appeared to be insignificant in the process. It appears that brewery waste water aids soluble phosphorus removal at the Milwaukee plants.

The cyclic removal of TP in an activated sludge plant was shown by the analyses of hourly influent and effluent samples for BOD, TP and SOP during a year's study. These cycles corresponded to the hourly changes in sewage composition and flows and clarifier sludge blanket build-up. At times TP removal efficiency was greatly reduced by the loss of solids from overloaded clarifiers at peak flows.

Continuous addition of ferrous sulfate waste pickle liquor to EP-ML at a 15 mg/L-Fe rate provided hourly effluent soluble phosphorus residuals of 0.05 mg/L-P. X-ray diffraction studies of freeze dried sludges showed iron present as vivianite.

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Key Words: Phosphorus removal, activated sludge process, process parameters, wastewater treatment, biological treatment.

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SECTION I

CONCLUSIONS

A three-year plant scale study on the phosphorus removal by an activated sludge plant conducted at Jones Island Plant, Milwaukee, Wisconsin, resulted in the following observations:

1. The Milwaukee plants on the average removed 80% of the TP from sewage. The effluent TP concentrations coincided with the hourly changes in sewage composition and flow, and at times with the hourly build-up of clarifier sludge blankets. The effluent TP concentrations increased as the sewage flow, BOD and TP concentrations increased. Low effluent TP concentrations were usually observed with low sewage flow, BOD and TP concentrations.

2. The relationship of total BOD removal to total soluble phosphorus removal was found to vary according to the day of the week; on the average, the ratios were 88:1 for weekdays, 62:1 for Saturdays, and 47:1 for Sundays.

3. Weekly plant scale phosphorus balances during a 37 week study showed that an average of 95.7% of the sewage phosphorus removed by both plants could be accounted for in the Milorganite produced. This indicated that the removal of waste sludge (as Milorganite) was the vehicle for withdrawal of phosphorus from the waste treatment system.

4. Overloaded clarifiers at peak flows resulted in lower TP removals due to spewing of solids over the weirs. However, the detention of solids for 2 to 3 hours at different sludge blanket depths had very little influence on the clarifier effluent SOP concentration.

5. A substantial release of SOP was observed when the RS was mixed with the screened sewage. The concentration of SOP in the resulting ML was 2 to 3 times greater than that expected from the calculated amount in a corresponding mixture.

6. The removal of TSP by MLSS appears to be related to MLSS metabolic activity as was shown by MLSS-O_2 uptake rate measurements along the aeration tank.

7. A loading study with the two plants showed that an average F/M and TP/M loadings of 0.291 and .011, respectively, resulted in slightly higher average SOP removals compared to the higher average loadings of 0.514 and 0.019, respectively.

8. There was a marked drop in the soluble phosphorus removal during the shutdown of the Milwaukee breweries in 1969, compared with the high soluble phosphorus removals before and after the shutdown. The rapid recovery of soluble phosphorus removal by both plants indicates the brewery waste water aids soluble phosphorus removal.

9. Aeration tank studies in the East Plant indicated that an air application rate of 0.86 cu. ft./gal. of influent or larger and a ML-DO of 2.0 mg/L beyond the tank turnpoint was adequate and effective in reducing soluble BOD to 10 mg/L and TSP to 0.5 mg/L-P at MLSS concentrations of 2530 to 2910 mg/L. A ML-DO of 1.0 mg/L beyond the tank turnpoint did not result in as much SOP removal as was observed with a ML-DO of 2.0 mg/L.

10. The quantity of insoluble phosphorus (58% for 1969) in Milwaukee sewage is unusually high compared to normally reported values for municipal waste waters. No significant differences were found in influent and plant effluent soluble iron, aluminum, calcium and magnesium concentrations. This indicated that very little insolubilization of phosphorus by these cations occur in the activated sludge process. It appears that the cationic fixation of phosphorus probably occurs in the sewage prior to its reaching the plant.

11. Limited X-ray diffraction studies on freeze dried WS samples revealed that some of the iron in the WS was in the form of a crystal-like iron orthophosphate, vivianite $Fe_3 (PO_4)_2 \cdot 8H_2O$.

12. Limited phosphorus removal studies with the addition of waste pickle liquor to the mixed liquor indicated that enhanced SOP removals can be achieved by iron addition. The waste pickle liquor appeared to have no effect on the ML biota.

SECTION II

RECOMMENDATIONS

The results of this three year study have shown that the City of Milwaukee Sewerage Commission's East Plant can consistently average 80% total phosphorus removal from sewage. A short term study of continuous iron addition, as ferrous sulfate waste pickle liquor, to the East Plant has demonstrated the feasibility of a long term plant study. The preliminary data indicated that it could be possible to consistently produce a plant effluent with a TSP residual of approximately 0.5 mg/L-P or less. It could also be possible to improve the plant total phosphorus removal efficiency from an average of 80% to an average of 90%.

A one year study to determine the long term effects of continuous iron addition on the 115 mgd East Plant and to compare its performance to the 85 mgd West Plant which will receive no additional iron is proposed. The effects of continuous iron addition upon mixed liquor flora, mixed liquor settleability, waste sludge conditioning requirements and plant physical facilities would be evaluated along with effluent phosphorus and iron concentrations.

This would require the continuous feeding of ferrous iron (as waste pickle liquor) to the mixed liquor feed channel of the 115 mgd East Plant. Twenty four hour composite samples of East and West Plant effluent would be analyzed to determine the ability of ferrous iron to increase phosphorus removal. Microscopic examination of mixed liquor samples would be utilized to determine if iron affected the mixed liquor culture.

Extension of the test period over one year would establish the feasibility of iron addition as a method for enhanced sewage phosphorus removal. If iron addition proves to be feasible it could provide an economic method of phosphorus removal for existing activated sludge plants, and provide effluents with consistently low phosphorus residuals.

The completed work has shown that excellent removal of phosphorus from sewage can be obtained in an activated sludge plant. However, due to the size of the operation (115 mgd) and limitations in the method of waste sludge removal (fertilizer production) it was extremely difficult to control and/or change the process parameters on a day to day basis. It is therefore suggested that consideration be given to modifying the East Plant. The modifications would be the isolation of two aeration tanks and one clarifier and a separated mixed liquor feed. This would provide a 12 mgd plant operated on its own return sludge, in which all process parameters could be controlled and varied as required to establish the mechanisms of phosphorus fixation in the activated sludge process.

SECTION III

INTRODUCTION

It has long been recognized that phosphates are one of the major factors contributing to the progressive fertilization of streams and lakes which result in frequent and highly objectionable algae blooms.

Although over 90% of the biologically oxidizable organic matter and suspended solids are removed in the conventional activated sludge process, the reduction of dissolved mineral nutrients is generally very low. Most municipal plants employing the activated sludge treatment process, report phosphorus removals from sewage of 20 to 30%. There are a few exceptions, such as the Milwaukee (1), San Antonio (2), and Baltimore (3) plants where phosphorus removals as high as 80% to 96% have been reported.

No significant conclusions have been reached as to the reason for such wide variation in the effectiveness of the conventional activated sludge process to remove total phosphorus from sewage. One group of investigators, Menar and Jenkins (4), hypothesized that based on a normal BOD of about 200 mg/L and total phosphorus of 10 mg/L-P in sewage, the biological removal of phosphorus in the form of waste activated sludge should be 20 to 30% and any additional removal observed is the result of the insolublization of phosphate by the soluble cations (mainly calcium and iron) present either in the hard carriage waters or coming from steel industries or both. The second group (Levin and Shapiro (5), and Vacker, et. al. (6)) hold the theory that the activated sludge microorganisms under optimum operating conditions can store phosphorus far in excess of their metabolic requirements (100 BOD: 1P) and have called this excess uptake "luxury uptake".

The Milwaukee Jones Island plants have been consistently showing good total phosphorus removals (usually over 80%). The two plants (East and West) are operated in parallel and each plant treats a part of the total flow. In 1967, the Federal Water Pollution Control Administration initiated a three year research and demonstration project with the Sewerage Commission of the City of Milwaukee. The objective of the study was to demonstrate and optimize the effects of the activated sludge process parameters on a plant scale for the removal of total phosphorus from sewage.

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SECTION IV

LITERATURE SURVEY

Sewage phosphorus removals by the activated sludge process have been reported by a number of investigators, Owens (7) 2 to 46%, Stone (8), 64 to 71%, for three Chicago waste water treatment plants Hurwitz (9) reports removals of 76.7%, 36.6%, and 53.9%.Some of the short term plant scale investigations made by the Federal Water Pollution Administration as summarized by Witherow (3) have indicated total phosphorus removals of 51 to 75% in the Northside plant of Amarillo and the Village Creek plant in Fort Worth. The Rilling plant in San Antonio and the Back River plant in Baltimore have been reported to consistently remove an average of 80% and 90% of the total phosphorus respectively.

Phosphorus has also been successfully removed from waste waters by using chemicals such as lime, alum, ferric chloride, ferric sulfate, ferrous sulfate, and sodium aluminate. These chemicals have been used to precipitate phosphorus in tertiary treatment by Owens (7), Lea, et. al. (10), Rohlich (11), Malhotra, et. al. (12) and Nesbitt (13). Chemicals have also been used to insolublize phosphorus in the biological treatment units by their addition to the aeration units, Tenney and Stumm (14), Barth and Ettinger (15), Eberhardt and Nesbitt (16), or by their addition prior to the primary sedimentation units, Rudolf (17), Neil (18), Schmid and McKinney (19).

A review of the current literature suggests that two schools of thought are being used to explain the wide variation in the phosphorus removals observed at different plants in the United States. Sawyer (20), Sekikawa, et. al. (21), Hall and Engelbrecht (22), Menar and Jenkins (4), support the theory that the biologically incorporated phosphorus in the activated sludge solids is between 2 to 3% phosphorus on the volatile mass basis and any additional removal is cationic. Menar and Jenkins (4) indicate that biological phosphorus removal is not affected by the sludge growth rate or by standard process operating parameters and that the phosphorus removal is directly proportional to the net sludge growth. This means that the phosphorus removed biologically in a conventional activated sludge sewage treatment plant would be in the range of approximately 100 parts of BOD removed to 1 part of soluble phosphorus removed. Based on an average BOD removal of 200 mg/L and influent total phosphorus content of 10 mg/L-P, about 20 to 30% of the influent phosphorus would be removed biologically.

The second theory was presented in papers by Levin and Shapiro (5), Borchardt and Azad (23), and Connell and Vacker (2); they indicated that activated sludge solids under certain conditions were capable of removing more phosphorus than they require for cell growth.

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The biological uptake of excess phosphorus was called "luxury uptake". They reported that luxury uptake was enhanced by high ML-DO concentrations, and the phosphorus incorporated by this mechanism was released from the solids by anaerobic or acidic conditions. They reported that luxury uptake leads to sludges containing as high as 7% phosphorus on the VSS basis.

Most investigations, Sawyer (20), Hall and Engelbrecht (22), Levin and Shapiro (5), were laboratory experiments to study the activated sludge process parameters effect on the removal of SOP from sewage. Connell and Vacker (2), Witherow (3), have reported the process parameter effects based on full scale plant studies which showed good phosphorus removals. Sawyer (20) found that an addition of glucose to increase the sewage BOD by 400 mg/L reduced the sewage phosphorus from 2.68 mg/L-P to 0.00 mg/L-P. Sekikawa, et. al. (21), Hall and Engelbrecht (22), and Levin and Shapiro (5), also observed higher phosphorus removals when the initial BOD concentration of the substrate was increased. Witherow (3) reported that the phosphorus removal in the aeration tank was affected by the BOD load applied to the tank and he observed good phosphorus removals with the influent BOD in the range of 118 to 202 mg/L. Menar and Jenkins (4) found that the phosphorus content of the activated sludge volatile solids did not vary significantly over a wide range of substrate removal rates and the weighted average per cent phosphorus on the VSS basis was 2.62%.

The effect of high initial phosphorus content of the substrate on phosphorus removal has been reported by Witherow (3). He observed good phosphorus removals when the influent phosphorus was in the range of 4.2 to 10.5 mg/L-P. Higher phosphorus levels in the influent resulted in decreased % phosphorus removals in the activated sludge process.

The effect of detention time on phosphorus removal has been reported by Srinath (24), Alarcon (25), Hall and Engelbrecht (22), Levin and Shapiro (5), Srinath's (24) data showed that the phosphorus and BOD removal rates appear to coincide, approximately 70% removal after one hour and then gradually increasing to 90% after five additional hours of aeration. Levin and Shapiro (5) observed over 70% soluble phosphorus removals in an aeration time of 3 hours. Witherow (3) recommends a modal detention of > 2.5 hours in the aeration tank for good phosphorus removal. Sekikawa et. al. (21) and Alarcon (25) found that after all the BOD had been consumed, further aeration of ML caused the release of phosphorus from the sludge solids due to cell oxidation (i.e., endogenous respiration).

There are divided opinions on the role of MLSS concentration in the removal of phosphorus in the aeration tanks. Hall and Englebrecht (22) and Sekikawa, et. al. (21) found MLSS concentrations had very little effect on the rate or the extent of soluble uptake.

Srinath, et. al. (24) reported that maximum phosphorus uptake was produced by 20 to 30 percent return sludge. Feng (26) observed low MLSS (500 mg/L) to effect the best phosphorus removals when the aeration rates were high (18 cu.ft./gallon of ML). Connell and Vacker (2) obtained maximum phosphorus removal at an average daily BOD loading rate of about 50 lbs. of BOD/100 lbs. of aeration solids. Witherow (3) observed good phosphorus removals with MLSS >1200 mg/L and loading rates ranging from 0.26 to 0.35 lbs. of BOD/lb. of MLSS/day.

Levin and Shapiro (5) found that ML pH had a pronounced influence on phosphorus removal, a pH range of 7 to 8 was most effective while pH values >8 and <6 resulted in phosphorus release from the sludge solids.

Rudolf (17) in 1947 reported a release of soluble phosphorus during anaerobic sludge digestion. In 1961, Alarcon (25) demonstrated that the soluble phosphorus content of ML decreased during aeration and increased when aeration was stopped. Campbell (27) reported that return sludges kept under anaerobic conditions at room temperature for four hours released phosphorus from the sludge solids into the liquid. Levin and Shapiro (5), Connell and Vacker (2), Hall and Englebrecht (22), and Witherow (3) indicate that a ML-DO level of approximately 2 mg/L was necessary for the optimum uptake of soluble phosphorus. Hall and Engelbrecht (22) and Connell and Vacker (2) found that the release of phosphorus from the solids back into the liquid (such as in the final clarifier) was not significant if a high dissolved oxygen level had been sustained during the second half of the aeration period.

SECTION V

PROCEDURES

MILWAUKEE WASTE WATER TREATMENT FACILITIES AT JONES ISLAND

The wastewater treatment system of the Sewerage Commission of the City of Milwaukee on Jones Island consists of the East and West Plant. The capacity of the activated sludge plants is 115 mgd, and 85 mgd respectively. The physical layout of these plants is shown in Figure 1. The Milwaukee plants serve a total drainage area of 410 square miles having a connected population of approximately 1,000,000. Combined sewers serve approximately 6.6% of the total area and the remainder of the area has a separate sewer system.

The volume of wastewater from this highly industrial area consists of approximately 22% industrial and 78% domestic wastewater (28). The daily average characteristics of screened sewage and some daily average operation data for 1967, 1968 and 1969 are given in appendix E. The wastewater flows through mechanically cleaned bar screens (1 inch openings) and then flows through a battery of eight grit chambers (8 x 8 x 90 feet long each) at a velocity of approximately one foot per second. Fine screenings are removed by passage of the degritted sewage through eight rotary drum screens having 3/32 inch slots. Approximately 60 wet tons of screenings and grit are removed and incinerated daily in a 5 stage multiple hearth furnace. The screened sewage flow is then divided between the two activated sludge plants (East and West).

After screening the sewage flows into aeration tanks where air is supplied through plate diffusers arranged in a ridge and furrow type pattern. Design detention time is 6 hours. Final sedimentation in peripheral feed clarifiers is accomplished during a 2 hour design time for detention. The waste sludge is disposed of by processing it into Milorganite fertilizer. Further details of the Jones Island plants can be found in reference 28.

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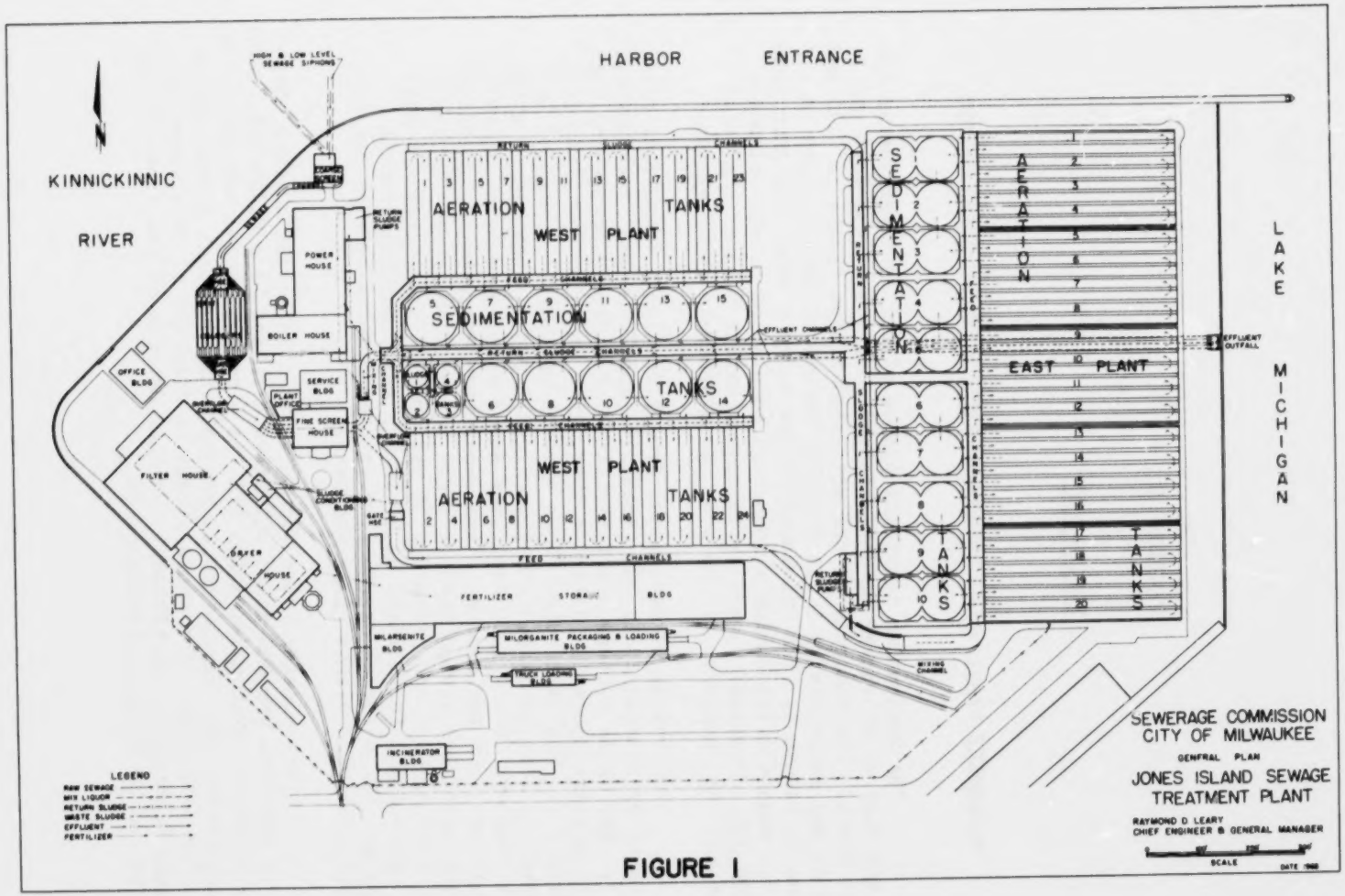

HARBOR ENTRANCE
KINNICKINNIC RIVER
LAKE MICHIGAN
HIGH & LOW LEVEL SEWAGE SIPHONS
AERATION TANKS
WEST PLANT
SEDIMENTATION
AERATION TANKS
WEST PLANT
SEDIMENTATION TANKS
AERATION
EAST PLANT
TANKS
POWER HOUSE
BOILER HOUSE
OFFICE BLDG
SERVICE BLDG
PLANT OFFICE
FINE SCREEN HOUSE
FILTER HOUSE
BLOWER HOUSE
SLUDGE CONDITIONING BLDG
FERTILIZER STORAGE BLDG
MILORGANITE PACKAGING & LOADING BLDG
TRUCK LOADING BLDG
MILARSENITE BLDG
INCINERATOR BLDG
EFFLUENT OUTFALL
LEGEND
RAW SEWAGE
MIX LIQUOR
RETURN SLUDGE
WASTE SLUDGE
EFFLUENT
FERTILIZER
SEWERAGE COMMISSION
CITY OF MILWAUKEE
GENERAL PLAN
JONES ISLAND SEWAGE TREATMENT PLANT
RAYMOND D. LEARY
CHIEF ENGINEER & GENERAL MANAGER
SCALE

FIGURE 1

SAMPLING AND ANALYTICAL TECHNIQUES

Sewage sampling - Initially, screened sewage samples were single grab samples which were used for the hourly study. Aliquots proportional to flow from these hourly samples were used to make the 24-hour composite sample.

On 6-13-68, a Phipps - Bird sewage sampler was put into operation to provide hourly sewage composites (30 - 200 ml. portions/hour). Aliquots proportional to flow from these hourly composites were used to make the 24 hour composite. This sampling procedure markedly reduced the fluctuations in the sewage phosphorus and BOD concentrations exhibited by the hourly grab samples.

Effluent sampling - Plant effluent samples were hourly grab samples. The 24 hour composites were prepared the same way as for sewage. Hourly grab samples of the plant effluent showed very little fluctuation in BOD and phosphorus concentrations from hour to hour compared to screened sewage hourly grab samples.

Others - All other samples used in short term studies were seven liter grab samples.

Analytical methods - Listed below are brief descriptions of the analytical methods and instrumentations used in this study. Some of the analytical methods used are described in the appendix and the instruments manufacturer operation manuals are listed in the references. Angel Reeves glass fiber filter pads (2.4 cm., 934AH) were used to provide the filtrates for the analyses of "soluble components".

Determination of phosphorus - Technicon Autoanalyzer as described in Appendix A was used. The Autoanalyzer was used only for SOP analyses because the Technicon acid digestion system, automatic sampler for liquids with colloidal suspended solids and the automatic filtration system were found to be inadequate.

Dissolved oxygen measurements - were made by a variety of instruments. The ML-DO was continuously monitored at the outlets of six EP aeration tanks by means of "galvanic cell" probes. Spot ML-DO measurements were made by a YSI Model 5418 probe and Model 51 meter. The YSI Model 5420 probe and Model 54 meter were used to determine the DO levels for the BOD determination. The MLSS-O_2 uptake rates were determined with a YSI Model 53 Biological Oxygen Monitor. The procedure used was as described in the suppliers manual (29) using 1 to 2 and 1 to 5 dilutions on each ML sample.

East Plant effluent turbidity - was continuously monitored by a Hach CR surface turbidimeter Model 1889. Spot turbidity measurements were made with a Hach Laboratory Turbidimeter Model 2100. The turbidimeters were operated and calibrated as described in manufacturer's "Instruction Manuals" (30) and (31).

The MLSS and RSSS concentrations - were ascertained by a procedure in use in the Milwaukee Sewerage Commission's Laboratory (Appendix B).

The total and total soluble cations concentrations (Fe, Al, Ca and Mg) - were determined on "ternary acid digestates" of the sample by means of an Atomic Absorption instrument (Instrumentation Laboratory, Inc. Model No. 153). The instrument operation and calibration were as described in the manufacturer's "Procedure Manual" (32).

Biochemical oxygen demand (BOD) - the "Azide Modification of the Iodometric method" for the BOD analyses as given in Standard Methods 12th edition (33) was compared with a modified procedure using a YSI Model 5420 probe and Model 54 meter to determine DO levels. The modified procedure is described in appendix (C). A comparative study of these methods showed good agreement.

A study to determine a factor for converting 4 day and 6 day BOD's to 5 day BOD's (1.14 and 0.93) showed good agreement with those reported by B. L. Goodman & J. W. Foster (34) of 1.13 & 0.91 respectively for sewage.

SECTION VI

RESEARCH PHASES, RESULTS AND DISCUSSIONS

CORRELATION OF ACTIVATED SLUDGE PROCESS PARAMETERS TO PHOSPHORUS REMOVAL ON A PLANT SCALE.

In this study, all pertinent data from the Milwaukee Sewerage Commission East Plant located on Jones Island for the 1968 year and for the 1969 year thru September 30 was transferred to IBM computer cards. The month of January, 1970 was used for the comparison study of 1968 $\log_e$ equation.

The data from these cards was then used to establish the variables included in this analysis. It was initially assumed that the percent of total phosphorus removed by the activated sludge process is a linear function of a set of process parameters (note : effluent soluble orthophosphate was considered as a variable not as a process parameter). The predictive equation of phosphate removal can then be expressed as:

$$Y = a_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6 + a_7x_7 + a_8x_8$$

a_1 = intercept of the regression line

a_i = regression coefficient for ith parameters, $i = 2, 3, \ldots 8$

where Y = % removal of total phosphate

x_2 = food to microorganism ratio (F/M)

F = lbs. of BOD/day
M = lbs. of volatile suspended solids (MLVSS)

x_3 = detention time (hours) in aeration tank

x_4 = cu. ft. of air/gallon of sewage

x_5 = mixed liquor suspended solids (mg/liter) (MLSS)

x_6 = dissolved oxygen in the effluent of aeration tank (mg/liter)

x_7 = $\frac{\text{total phosphate in the influent in lbs/day (TP)}}{\text{microorganisms (M)} \quad \text{(MLVSS)}}$

x_8 = soluble orthophosphate in the effluent (mg/liter)

Another set of statistical evaluations was made on the basis of the assumption that the distribution of parameters influencing percent removal of total phosphate (x_2, x_3, ... x_8) is exponential, such that the logarithm of the dependent variable (percent removal of total phosphate) varies linearly with the logarithm of the independent variables. The regression equation for this assumption can be expressed as

$$Y = a_1 x_2^{a_2} x_3^{a_3} \cdots x_8^{a_8}$$

The data was analyzed in the following groups with several trials in each group.

1968 Data - Natural Form (362 cards)
1969 Data - Natural Form (273 cards) 1/1/69 - 9/30/69
1968 + 1969 Data - Natural Form (601 cards)
1969 excluding brewery strike period - Natural Form (217 cards)
1968 Data - Logarithmic Form (342 cards)
1968 Data - Logarithmic Form (234 cards)
1969 pata - Logarithmic Form (259 cards)
1968 + 1969 Data - Logarithmic Form (601 cards)
1969 excluding brewery strike period - Logarithmic Form (217 cards)

During 1969, a brewery strike from June 9 to July 15 caused significant differences to occur at the sewage treatment plant. Thus, the 1969 data was analyzed including and excluding the strike period to determine the effect of large volumes of brewery wastes on the Milwaukee treatment plant.

Method of analysis - A multiple regression analysis was performed with the data from 1968 and 1969 in both the natural form and in the logrithmic form (log to the base e) and is explained completely in a separate report (35).

Results - Several equations were developed for each set of data both in natural form and in logarithmic form. Generally the significant variables were:

x_2 F/M ratio

x_3 Detention Time

x_5 Mixed Liquor Suspended Solids

x_7 TP/M ratio

As an example, the best equation developed for the 1968 data was the following: Equation Number 1

$$\text{Log}_e Y = 3.55118 - 0.02855 \text{ Log}_e x_2 + 0.05819 \text{ Log}_e x_5 - 0.10076 \text{ Log}_e x_7$$

This equation used data from those days (234) in 1968 when the effect of overloaded clarifiers was not evident. This was determined by using the following criteria:

1. Effluent BOD < 20 mg/l
2. Effluent SS < 20 mg/l
3. Clarifier Blanket < 14'
4. (Total P - Soluble P) in the effluent < 0.4 mg/l-P

If any 3 of the above 4 criteria were satisfied, the data for the respective date in 1968 was accepted and analyzed in the multiple regression analysis.

The above equation was then tested against the 1969 data from January 1 to September 30, minus the June 9 to July 15 brewery strike period, plus January 1, 1970. The same criteria for overloaded clarifiers was used. A total of 256 days during the above period was compared.

Comparison is best shown as follows by relating the measured % phosphorus removal to that removal calculated in the above equation (1).

On 193 days, the calculated % removal was within 10% of the measured % removal.

On 115 days, the calculated % removal was within 5% of the measured % removal.

On 102 days, the calculated % removal was within 4% of the measured % removal.

On 86 days, the calculated % removal was within 3% of the measured % removal.

On 65 days, the calculated % removal was within 2% of the measured % removal.

On those days (196 out of 256) when the measured % removal was > 80%, the calculated % removal was within 10% except for 3 days.

A conclusion can be drawn from this analysis. When the removal of phosphorus exceeds 80% in the Jones Island plant, the significant parameters are Food/Microorganism ratio, mixed liquor suspended solids and Total Phosphorus/Microorganism ratio as related in Equation (1).

DEMONSTRATION OF CYCLIC REMOVAL OF PHOSPHORUS FROM SEWAGE BY AN ACTIVATED SLUDGE PLANT.

In the literature prior to 1966, the majority of the studies reported on phosphorus removal from sewage by the activated sludge process were small scale laboratory experiments under ideal conditions. A few plant scale investigations were reported but were limited to the study of SOP levels in the effluent from the aeration tanks and not in the effluent from the secondary clarifier. Very little information from long term studies was available on an activated sludge plant's capability to remove total and soluble phosphorus from sewage on a hourly basis. At the outset of this investigation, the influent and the effluent of a 115 mgd activated sludge plant were monitored on an hourly basis, 7 days a week. This initial approach was taken to study the effects of plant operation practices, sewage flow and composition on the hourly removal of sewage phosphorus by an activated sludge plant. This study was carrried over a period from 12-3-67 to 12-19-68.

Screened sewage and East Plant effluent grab samples were taken every hour and stored under refrigeration. These samples were analyzed the next day for BOD, TP and SOP. The data from the hourly grab samples of screened sewage exhibited extreme fluctuations, whereas the data from the effluent hourly grab samples showed very little fluctuation. Data for each hour for each day of the week was averaged because the data showed that sewage total phosphorus removal was influenced by the sewage composition and volume of flow, and by operation of the clarifiers which varied from day to day. For example, on Sunday and Saturday sewage volume of flow, BOD and phosphorus concentration were consistently lower than those for Monday thru Friday. The data for Monday thru Friday was considered separately because insufficient capacity in the dewatering facilities on those days controlled the MLSS level and the clarifier blanket depths. Because of this, it was usually not possible to maintain a given MLSS level in the aeration tanks from day to day during this study.

The averaged hourly data for the screened sewage and for the East Plant effluent are presented in Figure 2. The East Plant effluent data was adjusted by 9 hours to compensate for the plant flow thru time. After this adjustment, the effluent data corresponded fairly close to the influent data.

Figure 2 exhibits the cyclic nature of phosphorus removal by the East Plant. It also demonstrates that three cycles occur during each week in the East Plant. These cycles are related to three sets of circumstances which occur weekly and may vary from week to week.

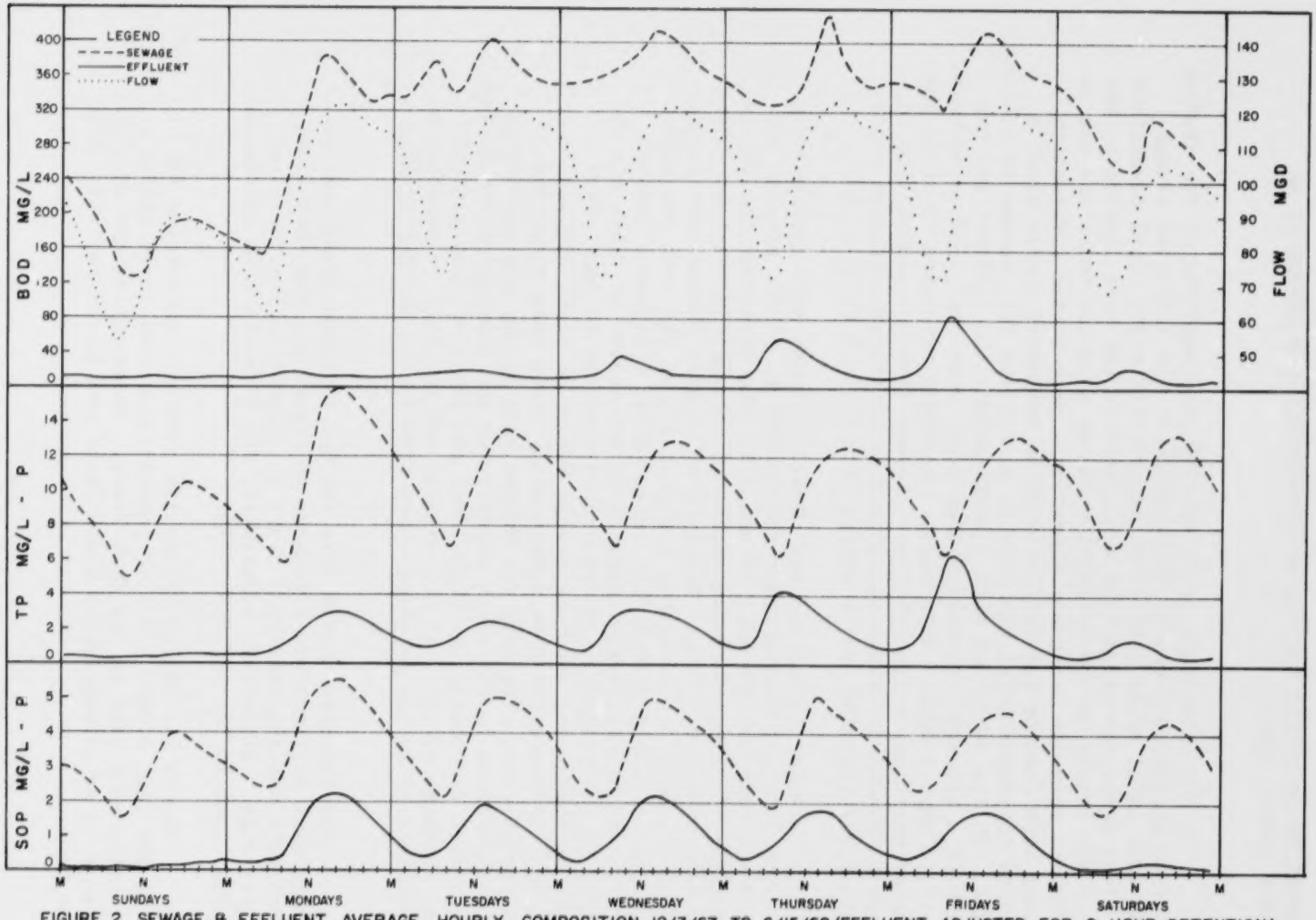


FIGURE 2 SEWAGE & EFFLUENT AVERAGE HOURLY COMPOSITION 12/3/67 TO 6/15/68 (EFFLUENT ADJUSTED FOR 9 HOUR DETENTION)

The first cycle was labeled the "Sunday Cycle". It started at approximately 4 PM (see Figure 2) on Saturday (actual effluent time would be 1 to 2 AM Sunday) and continued until 6 AM Monday (actual effluent time, 3 to 4 PM Monday). The reduced sewage flow and BOD concentrations occurring during this cycle resulted in increased detention time and air application rate which in turn increased the ML-DO. The most striking characteristic of the Sunday Cycle was the consistency of the low levels of TP, SOP and BOD in the East Plant effluent from hour to hour, which averaged below 1.0 mg/L-P, 0.5 mg/L-P and 10 mg/L respectively. This period appeared to have the most favorable conditions for the activated sludge process to remove phosphorus from sewage.

The second cycle was called the "Daily Cycle". It differed from the first in that the effluent TP, SOP and BOD levels fluctuated over a 24 hour period in the same manner as the sewage flow and nutrient (phosphates) concentrations. This cycle started with peak flow and BOD levels at 2 to 3 PM on any day and gradually decreasing to the lowest values at about 3 AM. The daily cycle occurred Monday thru Friday as shown in Figure 2.

The third cycle was the "Weekly Cycle". The main characteristics of this cycle were the increase in the amount of insoluble phosphorus and BOD in the plant effluent starting from Monday which kept on increasing as the week progressed. This cycle was found to be dependent on the mixed liquor settleability and the capacity of the dewatering facilities for removing the waste sludge. Most of the time dewatering facilities were unable to remove the waste sludge as fast as it was produced. As a result, the unremoved waste sludge accumulated in the clarifiers causing higher sludge blankets during hours of peak flow on certain days. The amount of waste sludge accumulated in the system generally increased from Monday to Saturday, resulting in high sludge blankets during the peak flow hours. The final result was that the overloaded clarifiers sometimes discharged MLSS over the weir during peak flow hours and caused an increase in the effluent BOD and insoluble phosphorus concentration as shown in Figure 2.

The effect of clarifier sludge blanket depths on the TP, SOP and SS concentrations of the East Plant effluent are summarized in Table 1 on the next page.

TABLE 1

EFFECT OF CLARIFIER SLUDGE BLANKET DEPTHS ON EP EFFLUENT QUALITY

Maximum Clarifier Blanket Depth Reached in 24 Hours	Daily Averages from Hourly Effluent Sample Data 12/3/67 to 9/15/68				Number of Days Observed
Feet	TP mg/L-P	SOP mg/L-P	Insoluble -P* mg/L-P	SS mg/L	
0 to 4	1.11	0.70	0.41	16	107
5 to 8	1.04	0.64	0.40	14	75
9 to 13.5	2.10	0.88	1.22	45	102

* Insoluble P = TP - SOP

The above data shows that the effluent SOP levels on the average did not change greatly with increasing sludge blanket depths.

PLANT STUDY OF THE EFFECT OF CLARIFIER BLANKET DEPTHS ON CLARIFIER EFFLUENT SOP RESIDUAL

It is well known that SOP is released by sludge solids when they are detained in the final clarifiers for extended periods of time. Thus, the release of SOP from the clarifier sludge solids could increase the clarifier effluent SOP concentration. If this occurred, the effects of the process parameters in removing SOP by MLSS during aeration would be obscured.

The effect of sludge detention time on the release of SOP from sludge solids was first studied in the laboratory. A typical laboratory experiment consisted of using a ML sample which had been taken from an aeration tank after six hours of aeration (and contained 0.3 mg/L - P of SOP). This ML sample was then divided into five portions which were placed into five one liter graduate cylinders and allowed to settle at room temperature (72°F). Then at hourly intervals (from one cylinder each hour) the supernatant was carefully removed in 200 ml aliquots (four in all). The supernatant fractions and the sludge fraction were then analyzed for SOP. The SOP release and diffusion data are presented in Figure 3. This experiment showed that the amount of SOP released from the sludge solids increased with increased sludge detention time as expected. However, as shown in figure 3, the majority of the released SOP remained in the quiescent sludge blanket fraction and only a small amount of released SOP diffused into the supernatant with time. This means that the clarifier effluent can contain some SOP released by the sludge solids detained in the clarifier by the process of diffusion. But, more important are clarifier operations during periods of high blanket and peak flows. The data indicates that it is possible that if the inflow ML causes turbulent conditions during periods of high blankets the clarifier effluent could contain SOP released by the solids detained in the clarifiers.

Plant studies to determine if clarifier sludge SOP release had a significant influence on the clarifier effluent SOP residual were also made. During a ten day period the ML effluent from an aeration tank (EP Tank #10), the ML influent to clarifier #5 and the final effluent from a clarifier (EP Clarifier #5) were sampled 5 times a day. The SOP content was determined on each sample.

The data in Table 2 showed that during this study period there was very little diffusion of SOP from the clarifier sludge blankets to the clarifier effluent.

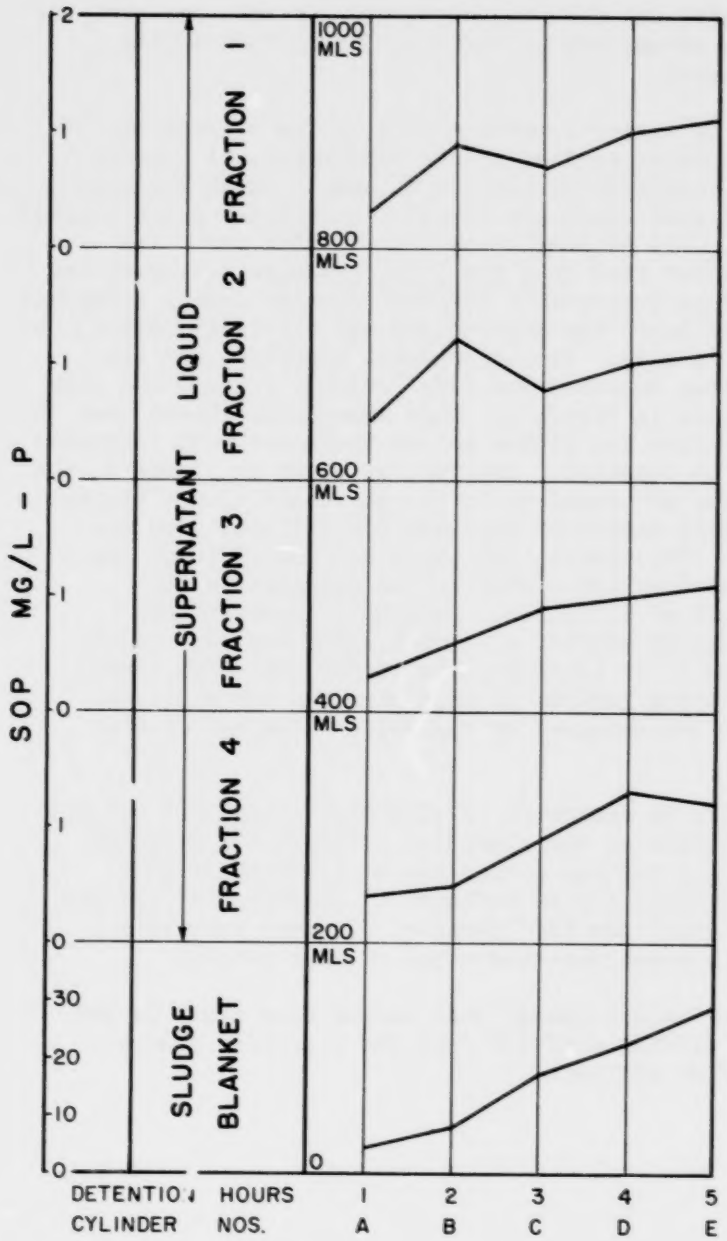


FIGURE 3 SOP RELEASE AND DIFFUSION FROM SLUDGE BLANKET VERSUS TIME

TABLE 2

COMPARISON OF SOP CONCENTRATION (MG/L-P)
OF AERATION TANK-10 OUTLET ML, CLARIFIER #5 ML-FEED,
CLARIFIER #5 EFFLUENT IN RELATION TO CLARIFIER BLANKET DEPTH

		SAMPLING TIME				
		7:30 AM	9:30 AM	11:30 AM	1:30 PM	3:00 PM
12-23	Outlet	0.44	-	0.05	0.06	0.05
1968	Feed	-	-	0.02	0.03	0.01
	Effluent	0.05	0.03	0.03	0.04	-
	Blanket Depth	6	6	7	8	8
12-24	Outlet	0.07	0.19	0.04	0.04	-
	Feed	0.03	0.06	0.04	0.02	-
	Effluent	0.22	0.13	0.07	-	-
	Blanket Depth	6	6	6	6	6
12-26	Outlet	0.19	0.20	0.26	0.35	0.36
	Feed	0.21	0.19	0.22	0.36	0.31
	Effluent	0.28	0.27	0.29	0.34	-
	Blanket Depth	4	4	4	4	4
12-27	Outlet	0.12	0.06	0.06	0.05	0.04
	Feed	0.34	0.19	0.08	0.05	0.06
	Effluent	0.37	0.24	0.13	0.07	-
	Blanket Depth	6	6	6	4	4
12-30	Outlet	0.67	0.61	0.42	0.32	0.39
	Feed	0.77	0.57	0.41	0.27	0.35
	Effluent	0.76	0.64	0.46	0.31	-
	Blanket Depth	1	1	1	1	1
12-31	Outlet	0.42	0.13	0.15	0.07	-
	Feed	0.66	0.14	0.13	0.11	-
	Effluent	0.63	0.37	0.19	-	-
	Blanket Depth	1	1	1	1	1
1-3	Outlet	1.4	1.3	1.1	0.88	0.83
1969	Feed	1.4	1.3	1.1	0.74	0.74
	Effluent	1.4	1.4	1.0	1.0	-
	Blanket Depth	1	1	1	1	1
1-4	Outlet	1.0	0.27	0.12	0.04	0.04
	Feed	0.92	0.24	0.06	0.06	0.07
	Effluent	1.5	0.70	0.16	0.09	-
	Blanket Depth	1	1	1	1	1
1-6	Outlet	3.1	3.0	3.0	2.7	2.7
	Feed	3.2	3.0	2.9	2.7	2.6
	Effluent	2.9	3.0	2.9	2.6	-
	Blanket Depth	1	1	1	1	1
1-7	Outlet	3.7	2.9	2.0	1.6	1.6
	Feed	4.0	2.7	1.8	1.2	1.3
	Effluent	3.7	2.7	1.7	1.3	-
	Blanket Depth	1	2	2	3	4

Blanket Depth - Feet

PLANT LOADING STUDY (F/M AND TP/M)

The first year's data indicated that the plant loading parameters, food to microorganism ratio (F/M) and total phosphorus to microorganism ratio (TP/M), appeared to be related to the removal of phosphorus by the activated sludge process. The effects of the F/M and TP/M loadings were studied simultaneously in both the activated sludge plants. The following loadings were chosen for this study:

Plant	Loading Ratios		Remarks
	F/M	TP/M	
East (EP)	0.300	0.012	Optimal Loading
West (WP)	0.600	0.024	High Loading

Under these loadings the EP was expected to yield good phosphorus removals as compared to the WP. It was further planned to reverse the above loadings between the two plants to see if the reverse results could be observed. The desired F/M and TP/M loadings were obtained by modifying the operations of both plants.

The pertinent data summarized in Table 3 are averages of the daily data for the periods indicated. In general, the data indicated that the high loadings (with average values of 0.514 F/M and 0.019 TP/M in the WP for period II) reduced the WP-SOP removal efficiency. The effect of the plant loadings on the daily EP and WP effluent SOP concentrations are shown in Figure 4.

The initial plan was to then reverse the plant loadings to see if the EP - SOP removal efficiency would be reduced. A viscous floating material appeared on the surface of the EP aeration tanks in period II but none was observed in the WP. The amount of this viscous material continued to increase in the EP until it was felt that this material and the continuation of the loading study would jeopardize the EP treatment efficiency. Regular defoaming agents were ineffective in breaking this foam. Vacuum skimming of the EP aeration tanks and clarifier feed channels reduced the amount of this foam and aided in overcoming this problem. Thus, the plant loadings were not reversed and this study was suspended. The sewage flow distribution and other process parameters were then changed in both plants and were gradually restored to their normal values in period III. Further details on this foam problem are given in appendix (D).

TABLE 3

AVERAGES OF DAILY DATA BY PERIODS

Period		I - Prior to Study Period 2/1 to 2/16- Dry Flow		II - Loading Study Period 2/17 to 3/10- Dry Flow		III - After the Study Period 3/11 to 3/18- Dry flow		IV - Period of Excessive Rainfall 3/19 to 3/31-Rain	
Plant		East	West	East	West	East	West	East	West
% Sewage Distribution		58	42	50	50	54	46	54	46
% Return Sludge		25	25	35	25	25	25	25	25
Air - Million cu.ft./day		133	107	133	107	133	107	118	107
SEWAGE									
SOP	MG/L-P	2.5		2.7		2.5		2.0	
TSP	MG/L-P	4.7		4.2		4.0		3.2	
TP	MG/L-P	9.8		9.7		9.9		8.5	
BOD	MG/L	258		260		306		247	
SS	MG/L	218		253		258		232	
FLOW	MGD	100.1	69.1	88.1	86.1	93.0	77.0	102.2	86.1
EFFLUENT									
SOP	MG/L-P	1.5	1.7	1.1	1.8	0.59	1.8	0.28	0.77
TSP	MG/L-P	1.9	2.2	1.4	2.1	0.94	2.2	0.44	0.97
TP	MG/L-P	2.2	2.4	1.9	2.9	1.3	2.6	0.82	1.5
BOD	MG/L	15.8	15.8	17.0	21.0	19.6	22.2	18.8	20.5
SS	MG/L	18	19	23	26	21	26	18	28
PROCESS PARAMETERS									
F/M		0.436	0.372	0.291	0.514	0.366	0.472	0.320	0.335
TP/M		0.0167	0.0142	0.0109	0.0188	0.0119	0.0152	0.0109	0.0118
MLSS	MG/L	2461	2513	2953	2273	2989	2657	3054	3294
DO	MG/L	4.3		3.1		3.9		3.1	
DETENTION	HRS	7.3	7.5	7.9	6.2	7.7	6.9	7.1	6.2
AIR CU.FT./GAL		1.34	1.57	1.53	1.26	1.44	1.40	1.18	1.26
% REMOVAL									
SOP		40.0	32.0	59.3	33.3	76.4	28.0	86.0	61.5
TSP		59.6	53.2	66.7	50.0	76.5	45.0	86.3	69.7
TP		77.6	75.5	80.4	70.1	86.9	73.7	90.4	82.4

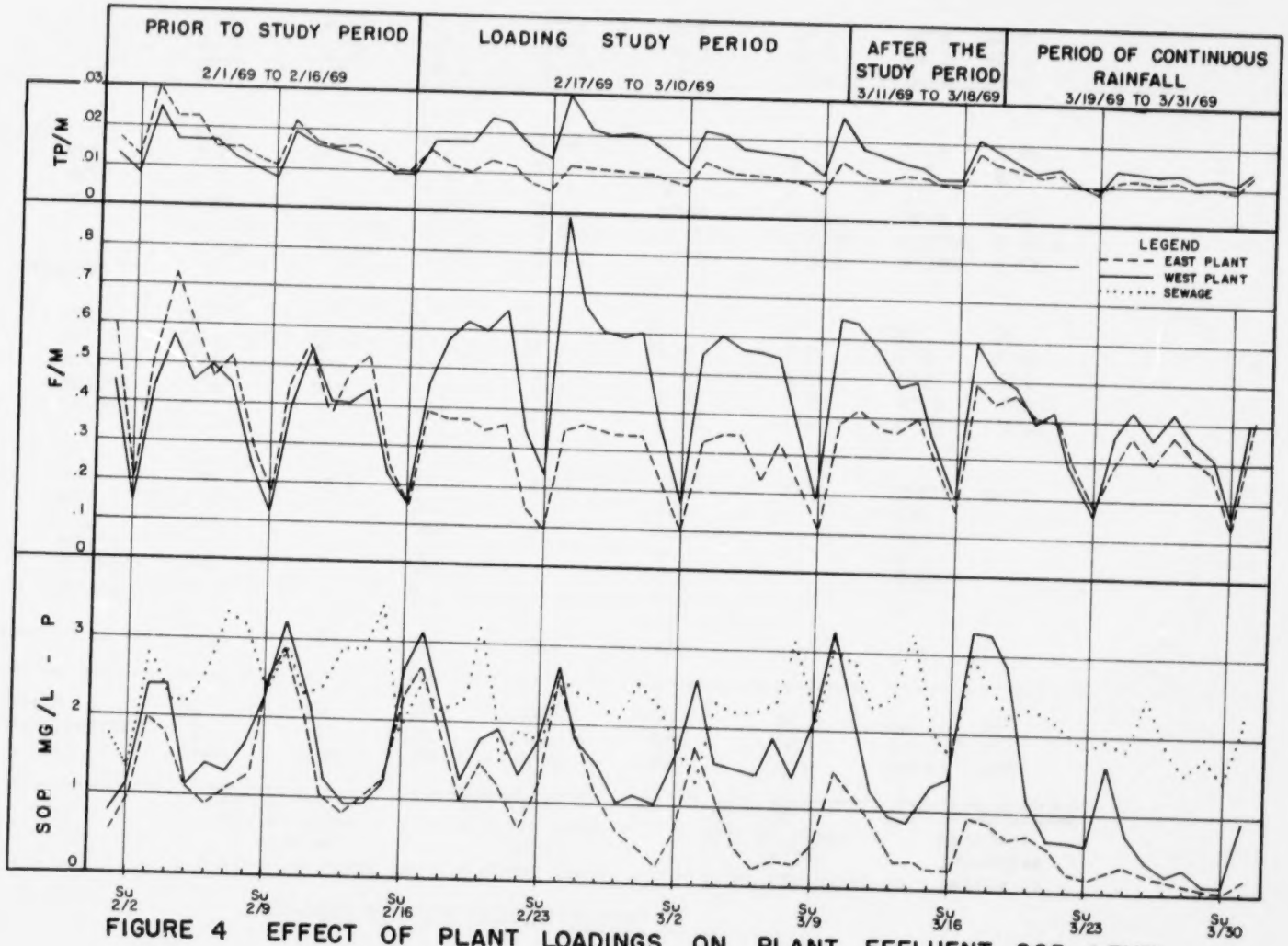


FIGURE 4 EFFECT OF PLANT LOADINGS ON PLANT EFFLUENT SOP LEVEL

Reduced TP/M and F/M loadings observed in period IV were caused by surface runoff due to continuous rainfall in this period (1.02 inches in 13 days) which affected influent composition and flow volumes. The reduced loadings frequently happen because of infiltration, since approximately 6.6% of the Commission's service area is served by combined sewers. Throughout this three year study, improved SOP removals in both plants were usually observed during such periods of continuous rainfall similar to the data shown in period IV.

EFFECT OF BREWERY WASTE LOAD

The effect of the industrial wastewater from the brewery industries in Milwaukee on the activated sludge plants operations were studied in 1969 when they were shut down due to a strike lasting from June 9 to July 15. The loss of the brewery industrial wastewater and the changes in sewage treatment plant operations made to offset the effects of this loss offered an excellent opportunity for another plant scale loading study (F/M and TP/M) in the East and West plants.

One of the significant effects of this industrial waste loss was a substantial reduction in the average sewage BOD when compared to the periods prior to and after the shutdown period as shown in Table 4. The data indicated that the Milwaukee breweries average BOD contribution comprised approximately 22% of the normal total BOD load. The BOD removal efficiencies for both plants were not affected; however, they continued to exhibit greater than 90% BOD removals.

It was also observed in a previous breweries shutdown in 1953 that the sewage BOD was substantially lower. During this previous period of low BOD the Milorganite nitrogen content decreased to an average of 5.31% from a normal value of 6.0%. During the 1969 shutdown, the plant operations were modified to reduce nitrification by decreasing the MLSS level, decreasing the detention time and decreasing the air applied in both plants. These plant operational changes were successful during the 1969 brewery shutdown, as evidenced by the small decrease in the average Milorganite nitrogen content, 5.75% N vs normal of 6.0% N.

During the 1969 strike period however, the TP removal efficiencies for both plants dropped from a monthly average of 85% to 63%. This decrease in TP removal efficiency was due to a significant reduction in the SOP removal efficiency from a monthly average of 80% to an average of 12.5% and 0.2% in the East and West plants respectively as shown in Table 4. The decreased SOP removal was apparently influenced by an increase in F/M, an increase in TP/M and a decrease in the MLSS levels, these are shown in Tables 4 and 5. After the breweries resumed their normal production and the sewage treatment plant returned to their normal operating parameters, the SOP removal efficiency for both plants improved tremendously.

During this long period of continuously poor removal of soluble phosphorus from sewage, one could expect to observe the RSSS phosphorus content to decrease. In Figure 5 are plotted the nitrogen and phosphorus contents of RS based on VSS (from the weekly composites for EP and WP return sludges). The data in Figure 5 shows that the RSVSS phosphorus did not decrease during this period of poor soluble phosphorus removal. Therefore, it may be assumed that a portion of

TABLE 4

SUMMARY PERIOD AVERAGES

Period		April, 1969		May, 1969		Breweries Shutdown June 9th - July 15th		August, 1969	
Plant		East	West	East	West	East	West	East	West
% Sewage Distribution		56	44	60	40	58	42	59	41
% Return Sludge		24	26	23	27	22	26	24	26
SEWAGE									
SOP	MG/L-P	2.1		2.0		2.1		2.3	
TSP	MG/L-P	3.3		3.1		3.6		2.8	
TP	MG/L-P	7.8		7.7		7.1		7.3	
BOD	MG/L	230		238		182		221	
SS	MG/L	210		238		196		218	
FLOW	MGD	109.4	85.0	112.1	74.9	110.9	79.9	115.6	81.5
EFFLUENT									
SOP	MG/L-P	0.31	0.32	0.27	0.26	1.9	2.1	0.50	0.41
TSP	MG/L-P	0.54	0.54	0.48	0.47	2.1	2.3	0.60	0.53
TP	MG/L-P	0.70	0.96	0.79	0.90	2.4	2.7	0.93	1.2
BOD	MG/L	9.9	13.2	17.5	15.2	10.5	12.0	9.4	12.9
SS	MG/L	11	18	19	31	12.6	16.5	15	28
PROCESS PARAMETER									
F/M		0.352	0.366	0.384	0.350	0.476	0.529	0.435	0.389
TP/M		0.012	0.012	0.012	0.011	0.019	0.021	0.014	0.013
MLSS	MG/L	2880	2970	2700	2770	1850	1870	2390	2590
DO	MG/L	3.2		1.7		3.6		4.9	
DETENTION	HOURS	6.7	6.3	6.5	6.9	6.2	5.3	6.1	6.2
AIR CU.FT./GAL		1.08	1.24	1.10	1.32	0.99	1.10	1.09	1.25
% REMOVAL									
SOP		86	84	87	87	12.5	0.2	79	81
TSP		84	83	85	85	40	35	80	82
TP		91	87	90	88	65	62	87	84

TABLE 5

COMPARISON OF PERIOD AVERAGES:

LOADING STUDY VS. BREWERIES SHUTDOWN

Period 1969		Loading Study Feb. 17th - Mar. 10th		Breweries Shutdown June 9th - July 15th	
Plant		East	West	East	West
% Sewage Distribution		50	50	58	42
% Return Sludge		35	25	22	26
SEWAGE					
SOP	MG/L-P	2.7		2.1	
TSP	MG/L-P	4.2		3.6	
TP	MG/L-P	9.7		7.1	
BOD	MG/L	260		182	
SS	MG/L	253		196	
FLOW	MGD	88.1	86.1	110.9	79.9
EFFLUENT					
SOP	MG/L-P	1.1	1.8	1.9	2.1
TSP	MG/L-P	1.4	2.1	2.1	2.3
TP	MG/L-P	1.9	2.9	2.4	2.7
BOD	MG/L	17.0	21.0	10.5	12.0
SS	MG/L	23	26	12.6	16.5
PROCESS PARAMETER					
F/M		0.291	0.514	0.476	0.529
TP/M		0.011	0.019	0.019	0.021
MLSS	MG/L	2950	2270	1850	1870
DO	MG/L	3.1		3.6	
DETENTION HRS.		7.9	6.2	6.2	5.3
AIR CU.FT./GAL		1.53	1.26	0.99	1.10
% REMOVAL					
SOP		59	33	12.5	0.2
TSP		67	50	40	35
TP		80	70	65	62

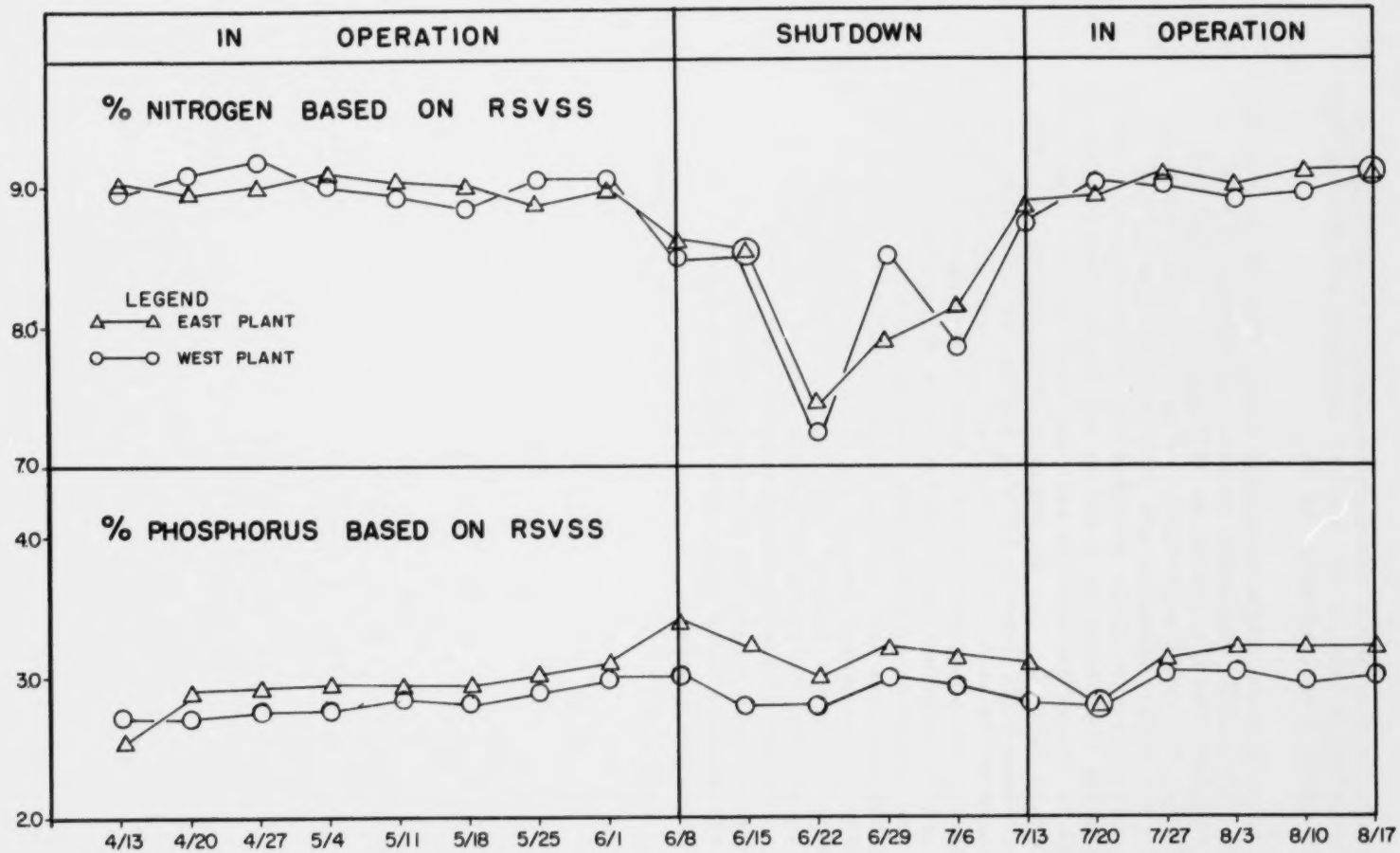


FIGURE 5 EFFECT OF BREWERIES SHUTDOWN ON R S COMPOSITION (WEEKLY COMPOSITES)

the sewage insoluble phosphorus was made available for assimilation by the microorganisms either in the initial aeration period with MLSS or in the subsequent recycling with the RS.

In the Milwaukee waste treatment plants the solids synthesized from the sewage BOD, suspended solids, and phosphorus are continuously removed from the system as Milorganite. During the breweries shutdown Milorganite production dropped significantly as shown in Table 6. Weekly balances are presented because it was difficult to calculate a reliable estimate for solids detention or withdrawal from the two plants on a day to day basis. The weekly pounds applied of sewage BOD and VSS also declined for the same period as shown in Table 6. The Milorganite phosphorus content did not appear to change significantly before, during, or after the shutdown as shown in Table 6. Phosphorus balance data showed that, on a weekly basis, the phosphorus removed from sewage was recovered in the waste solids withdrawn from the system as Milorganite. It appears that the reduction in phosphorus removal observed during the breweries shutdown was due to insufficient synthesis of solids for the quantity of phosphorus present in the sewage. In the Milwaukee plants the amount (and/or efficiency) of phosphorus removed from sewage appears to be influenced more by the amount of solids produced in the activated sludge process than by the activated sludge process parameters studied. In addition, it appears that the brewery waste water aids soluble phosphorus removal at the Milwaukee plants.

TABLE 6 RELATION OF PHOSPHORUS REMOVED TO SOLIDS SYNTHESIS
(1969 WEEKLY DATA)

WEEK OF	SOLIDS PRODUCED (DRY BASIS)* TONS WEEK	% P	TONS PHOSPHORUS	TONS APPLIED/WEEK (BOTH PLANTS) PHOSPHORUS	BOD	VSS	BREWERIES OPERATION
3-30 to 4-5	1376	2.25	31.0	44.8	1292	1411	
4-6 " 4-12	1682	2.26	38.1	47.0	1451	1491	
4-13 " 4-19	1650	2.27	37.5	41.3	1064	1293	
4-20 " 4-26	1834	2.18	40.0	44.8	1407	1346	IN
4-27 " 5-3	1655	2.23	36.9	42.8	1358	1324	OPERATION
5-4 " 5-10	1537	2.30	35.4	42.5	1335	1456	
5-11 " 5-17	1348	2.34	31.5	44.5	1349	1503	
5-18 " 5-24	1656	2.28	37.8	42.4	1218	903	
5-25 " 5-31	1640	2.30	37.7	40.4	1298	963	
6-1 " 6-7	1148**	2.35	27.0	41.3	1189	942	
6-8 " 6-14	1547***	2.57	39.8	43.7	1098	917	
6-15 " 6-21	1309	2.59	33.9	44.0	1139	960	
6-22 " 6-28	1076	2.38	25.6	37.6	1014	848	SHUTDOWN
6-29 " 7-5	841	2.19	18.4	30.5	829	659	
7-6 " 7-12	1026	2.30	23.6	37.9	957	775	
7-13 " 7-19	1171	2.30	26.9	39.3	1013	772	
7-20 " 7-26	1447	2.17	31.4	-	1251	948	
7-27 " 8-2	1446	2.33	33.7	35.1	1260	937	
8-3 " 8-9	1509	2.43	36.7	40.4	1167	954	IN
8-10 " 8-16	1678	2.54	42.6	44.8	1389	1093	OPERATION
8-17 " 8-23	1545	2.53	39.1	44.3	1190	1053	
8-24 " 8-30	1549	2.63	40.7	41.9	1423	1091	

NOTE *Milorganite production adjusted to account for either solids detention or withdrawal from the system.

**Abnormally low Milorganite production due to a holiday and the dewatering facilities shut down for two and a half days.

***High Milorganite production because the MLSS levels in the system were reduced from a weekly average of 2800 mg/L to the low level of 2000 mg/L (± 400) for the East Plant.

PLANT SCALE PHOSPHORUS BALANCES

The phosphorus balances shown in Table 7 were made to check the accuracy of phosphorus and plant flow data obtained in this project. The influent and effluent TP contents were determined by a Ternary Acid Digestion procedure (as described in Appendix A). The Milorganite phosphorus content was determined by the gravimetric AOAC Quinoline Molybdate Method 2.023 and 2.024 (36).

Phosphorus recovered in the Milorganite was compared with that removed from the influent by the two plants. The initial phosphorus balance calculations were made with the daily data but it was found too difficult to accurately account for phosphorus associated with the solids in the system. The phosphorus balances using weekly phosphorus removals, plant flows, and Milorganite production data were considered more realistic. The estimated solids storage in the system on a weekly basis usually exhibited less fluctuation than on a daily basis.

An average of 95.7% of the phosphorus removed by both plants could be accounted for in the Milorganite produced over the 37 week period. As evidenced by the weekly phosphorus balances as shown in the Table 7, plant phosphorus and flow data were reasonably accurate.

The phosphorus balances for both plants established the high phosphorus removals by the Milwaukee Sewage treatment plants and demonstrated that the phosphorus was removed from the process as Milorganite produced from waste sludge.

TABLE 7

CALCULATED WEEKLY PHOSPHORUS RECOVERIES
#TP Removed/Week in 1969

Weekly Period	WP	EP	Both Plants	Milorganite	% (*) Phosphorus Recovery
Feb. 10-16	29,840	40,026	69,866	69,388	99.3
17-23	38,559	32,206	70,765	69,056	97.6
24-2	37,355	49,009	86,364	72,338	83.8
Mar. 3-9	32,113	37,828	69,941	66,709	95.4
10-16	32,914	41,058	73,972	66,439	89.8
17-23	28,574	45,337	73,911	69,572	94.1
24-30	34,805	44,857	79,662	67,910	85.2
31-6	34,851	44,903	79,754	65,582	82.2
Apr. 7-13	33,960	44,452	78,412	71,610	91.3
14-20	36,024	46,841	82,865	78,744	95.0
21-27	30,261	45,568	75,829	74,802	98.6
28-4	33,297	46,195	79,492	70,800	89.1
May 5-11	30,334	43,771	74,105	69,986	94.4
12-18	29,696	45,568	75,264	68,459	91.0
19-25	31,257	45,974	77,231	69,544	90.0
26-1	29,851	46,422	76,273	77,982	102.2
June 2-8	22,135	38,708	60,843	48,445	79.6
9-15	36,266	49,028	85,294	86,939	101.9
16-22	24,819	41,953	66,772	72,105	108.0
23-29	18,120	30,653	48,773	52,837	108.3
30-6	17,325	22,268	39,593	40,795	103.0
July 7-13	16,142	21,467	37,609	36,681	97.5
14-20	21,474	31,392	52,866	46,336	87.6
21-27	-	-	-	-	-
27-2	21,762	34,216	55,978	63,760	113.9
Aug. 3-9	29,779	40,796	70,075	69,294	98.9
10-16	34,007	45,022	79,029	74,771	94.6
17-23	30,575	48,187	78,762	75,874	96.3
24-30	23,845	43,496	67,341	74,090	110.0
31-6	17,906	29,777	47,683	51,729	108.4
Sept. 7-13	24,421	43,529	67,950	64,497	94.9
14-20	22,690	37,858	60,548	57,753	95.4
21-27	26,993	42,041	69,034	64,691	93.7
28-4	9,479	46,953	56,432	58,232	103.2
Oct. 5-11	10,554	38,166	48,720	56,726	116.4
12-18	30,682	46,181	76,863	64,400	83.8
19-25	37,657	59,887	97,544	70,896	72.7
26-1	30,508	44,977	75,485	67,691	89.7
Nov. 2-8	33,277	49,807	83,084	78,371	94.3
9-15	34,707	49,251	83,958	76,175	90.7
16-22	35,758	48,412	84,170	71,562	85.0
23-29	28,857	41,398	70,255	64,377	91.6
Average % Recovery					95.7

(*) %Recovery = (#TP removed in Milorganite ÷ #TP removed in the plant) X 100

RELATIONSHIP BETWEEN TOTAL BOD REMOVAL AND TSP REMOVAL IN AN ACTIVATED SLUDGE PLANT (BOD_R/TSP_R)

Sawyer (20) studied the removal of BOD in conjunction with soluble phosphorus removal by the activated sludge process. He demonstrated in the laboratory, that by adding additional BOD (as glucose) he could obtain increased soluble phosphorus removal. From this work he concluded that 100 pounds of BOD were removed for each pound of soluble phosphorus in the activated sludge process. Hall and Engelbrecht (22) concluded from their studies that 80 to 110 pounds of COD were removed per pound of soluble phosphorus. It was decided to determine how applicable this concept was on a plant scale.

The BOD to TSP removal ratios (i.e., BOD_R/TSP_R) for both plants were calculated from the daily 24 hour sewage and effluents composites data. The calculated removal ratios from 2/9/69 to 11/30/69 are presented as frequency diagrams in Figures number 6 and 7. The data used in these diagrams are for periods of normal operating conditions.

The magnitude of the BOD_R/TSP_R ratio appears to be dependent on the day of the week as shown in Table 8.

TABLE 8

Average BOD_R/TSP_R Ratios

Plant	Weekdays	Weekend Days	
	Monday thru Friday	Saturday	Sunday
West Plant	86	60	44
East Plant	90	64	50

The data appears to indicate that in the Milwaukee activated sludge plants the removal of soluble phosphorus from sewage is not dependent on the removal of total BOD as we always observed greater than 90% BOD removals.

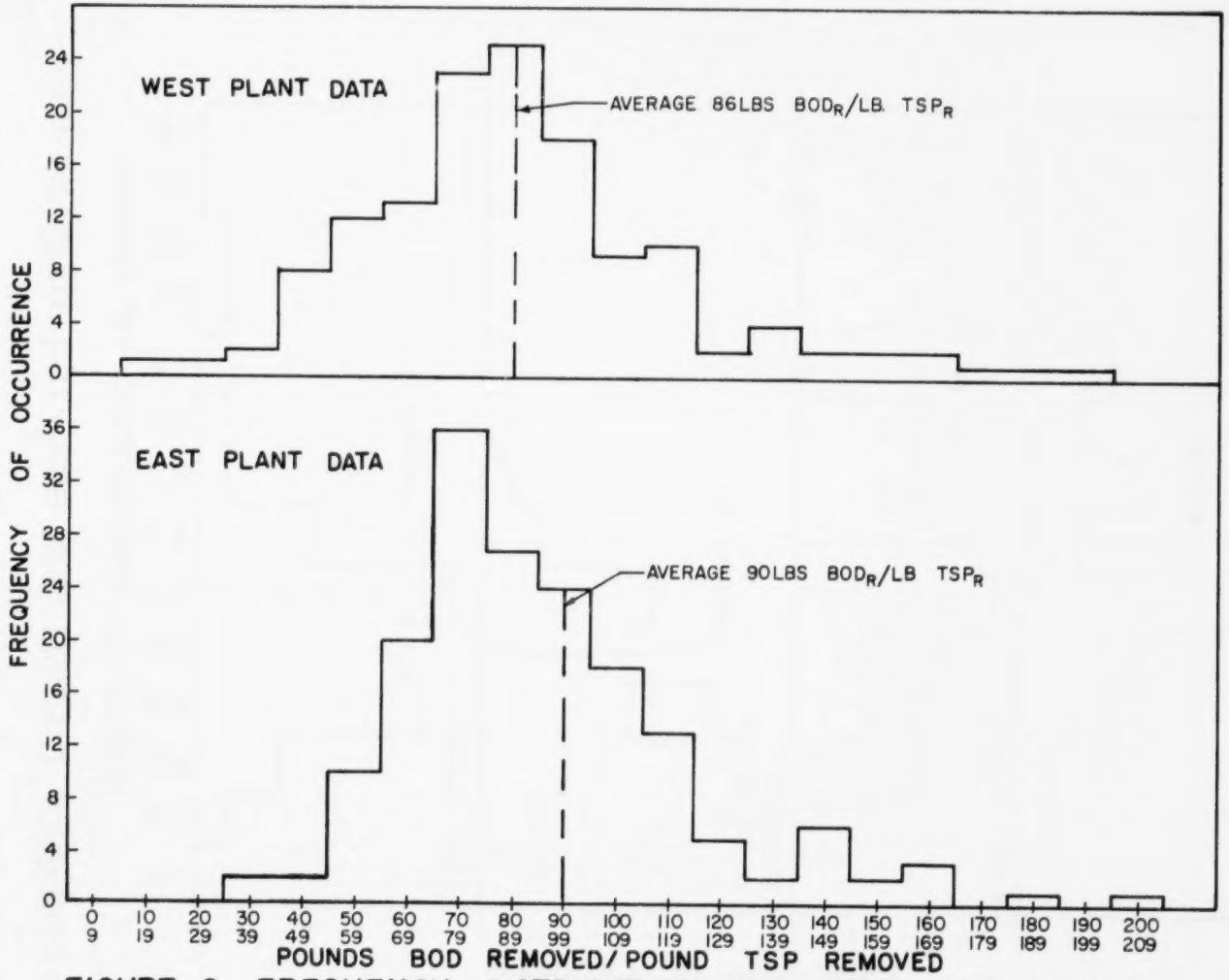
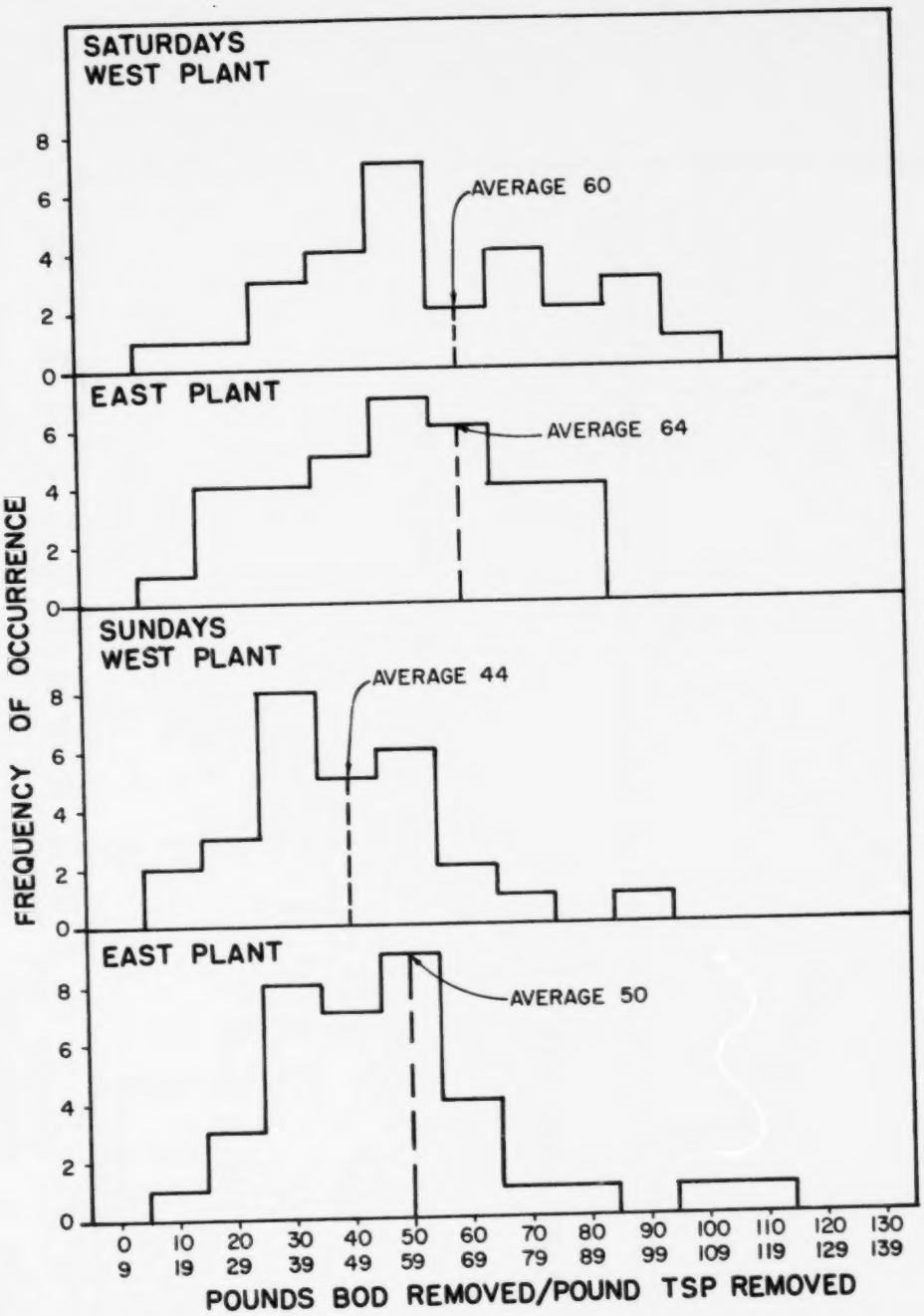


FIGURE 6 FREQUENCY DISTRIBUTION BOD$_R$ / TSP$_R$ WEEKDAY DATA



FREQUENCY DISTRIBUTION BOD_R/TSP_R WEEKEND DATA

FIGURE 7

STUDY OF SOLUBLE PHOSPHORUS UPTAKE IN EAST PLANT AERATION TANKS (GENERAL)

Eight separate studies were made during the course of two years on soluble phosphorus uptake in the aeration tanks. The ML detention time and air application rates were kept fairly constant at 6 hours and 3300 to 3500 cfm respectively. No attempt was made to control the MLSS levels and the F/M and TP/M loadings. Thus, they were the varying parameters which affected the ML-DO level and phosphorus removal efficiencies.

ML Spot samples (over a six hour period) were taken at each hour along the aeration tank and brought immediately to the laboratory and filtered. At the location from which the ML samples were taken the ML-DO was also measured. The ML filtrates were analyzed for SOP and/or TSP, soluble BOD, and pH. The SS were also determined on the ML samples. In addition, the zero hour detention grab samples of screened sewage and RS samples were analyzed for SOP or TSP.

The data from the majority of these studies were inconclusive because the studies were conducted on influent arriving at 8 to 9 AM when the influent BOD, TP and SOP concentrations were near their lowest average concentration in the twenty four hour period (see Figure 2). As a result, practically no dramatic differences in effluent residual SOP were observed which could be related to the process parameters under investigation.

It was consistently observed in these studies, that the SOP concentration of ML resulting from the mixing of screened sewage and RS in the mixing and ML feed channel as well as at zero hour aeration time in the aeration tanks was usually 2 to 3 times greater than the expected calculated SOP concentration in a corresponding mixture of sewage and RS. Also, at times the concentration of ML-SOP was greater than the sewage TP. It is unlikely that all the sewage insoluble phosphorus could be instantly converted to SOP when sewage is mixed with RS. Also, it is well known and easily demonstrated that the RSSS readily release SOP under anaerobic conditions. The RS was therefore considered as the logical source for the SOP increase in the ML.

Sewage and effluent samples were also analyzed for SOP and TSP in several studies. The difference between TSP concentration and SOP concentration in the sewage was consistently greater than 1 mg/L-P. In the aeration tank effluent, however, as well as in the plant effluents, the difference between TSP concentration and SOP concentration was consistently only 0.2 - 0.4 mg/L-P. This indicated, that in the activated sludge process the MLSS rapidly degrade or remove and retain soluble poly-and organic-phosphorus compounds.

EFFECT OF MLSS-O_2 UPTAKE RATES AND AIR APPLICATION RATES ON SOLUBLE PHOSPHORUS UPTAKE IN AN AERATION TANK.

In the activated sludge process the aerobic microorganisms require C, P, N, etc., from sewage in order to maintain their metabolic and reproduction activity. The amount of dissolved oxygen in the ML is dependent on the air application rate, the oxygen transfer efficiency of the aeration devices employed, and the oxygen demand rate of the microorganisms. The aerobic microorganisms in the ML also require sufficient amounts of dissolved oxygen for these activities.

Numerous reports in the literature have shown that the ML dissolved oxygen level is a significant activated sludge process parameter affecting soluble phosphorus removal (2,3,5,22). Accordingly, the effect of air application rate was evaluated using three tanks of the East Plant. This experiment was not performed on a plant scale because the MLSS level and plant loadings could not be controlled from day to day.

Oxygen utilization rate measurements have been frequently used to assess the metabolic activity or proportion of viably active cells in MLSS. In the literature no information was discovered on the relation of MLSS-O_2 uptake rate to ML-soluble phosphorus levels. The establishment of such a relationship would provide a means to assess the MLSS capability to remove soluble phosphorus in the activated sludge process.

Preliminary DO-profile studies of aeration tanks resulted in the selection of tanks 8, 9, and 11 of the East Plant for this study because these tanks had similar air distribution patterns (Figure 8). The ML flows to the three tanks were maintained at 7.5 mgd each with 30% RS to provide 6 hours detention time in each tank. The experiments were started at 2 PM when the ML oxygen demand rate due to high sewage BOD was usually at its peak. The air application rates tested during this four day study were as follows in Table 9.

TABLE 9

AIR APPLICATION RATES

Tank No.	CFM	Cu. ft./gal sewage	
8	2300	0.57	33% below normal
9	3500	0.86	Normal Rate
10	4700	1.16	33% above normal

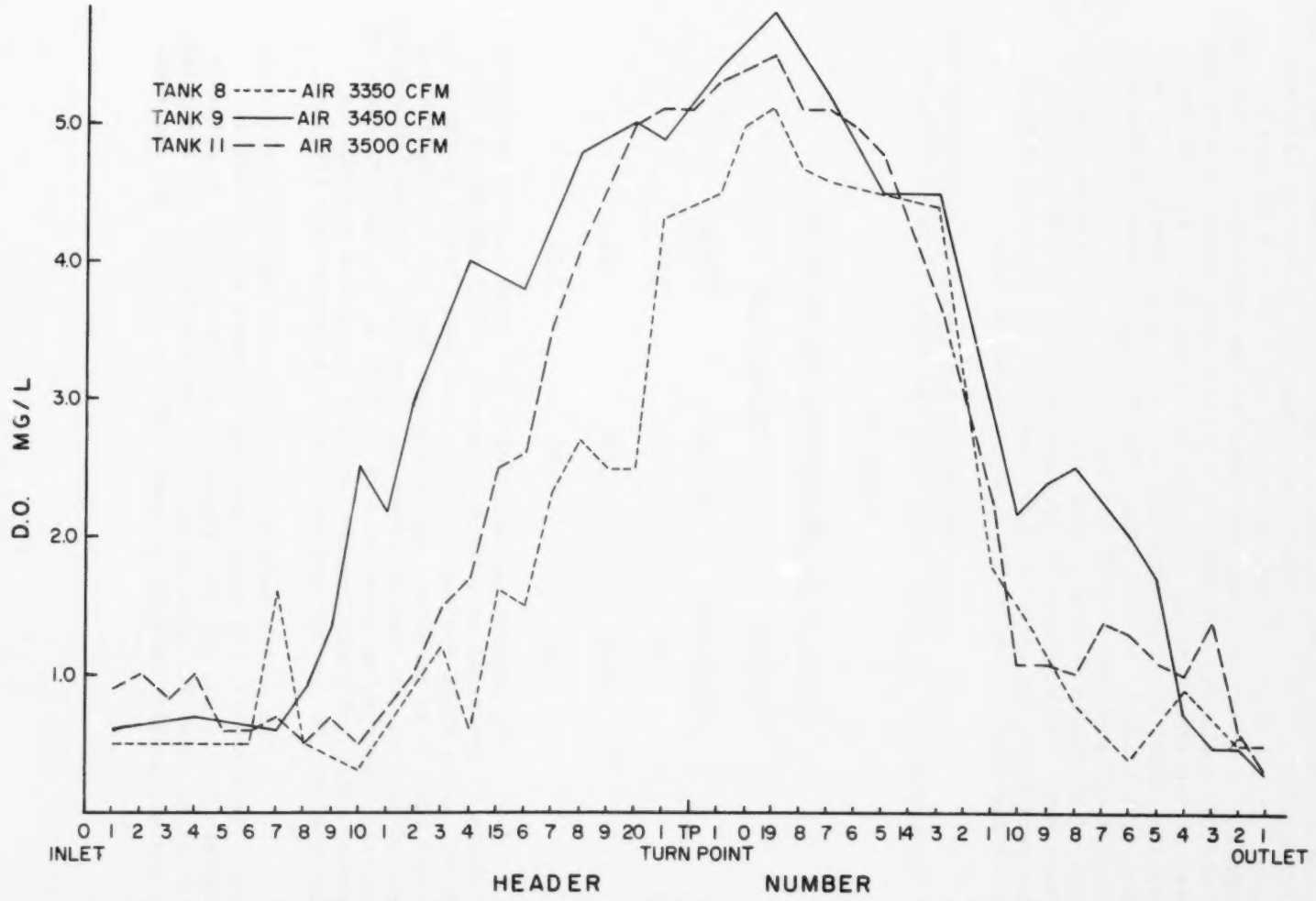


FIGURE 8 AERATION TANKS DO PROFILES (9-30-1969, 8:00 A.M.)

The changes observed in the tank DO-profiles resulting from these air application rates are shown in Figure 9. The difference in the DO-profiles given in Figure 8 and Figure 9 is partly due to the different BOD loadings on these tanks when the DO-profile data was taken. At the start of each daily run, the 1 PM to 2 PM hourly composite of screened sewage was taken to the laboratory for BOD, SS, TP and TSP analyses. In addition a 7 liter grab sample of EPRS was taken at the same time and analyzed for SS and TSP. At 2 PM (zero detention time) ML-DO readings and a 7 liter grab sample of ML was taken at the inlet of each tank. The ML samples were immediately filtered and analyzed for TSP and soluble BOD. A portion of the unfiltered ML sample from each tank was analyzed for SS, pH, and MLSS-O_2 uptake rate. This procedure was repeated every hour at sampling locations along the aeration tanks based on the detention time to follow the plug flow of ML through the aeration tank.

The ML final pH levels did not change significantly due to the changes in air application rates as shown below in Table 10.

TABLE 10

Effect of Air Application Rate on ML pH

Air Rate	Average ML pH	
cu.ft./gal	Initial	Final
0.57	7.40	7.24
0.86	7.40	7.28
1.16	7.41	7.34

The process parameter data for these runs as presented in Table 11 are based on 6 hours detention, 115.5 mgd sewage flow, 30% RS, and a MLVSS content of 68.9%. The data, listed in Table 11, showed that in an aeration tank at a given time the air application rate of 0.57 cu. ft./gal of sewage was inadequate for good phosphorus removal. However, an aeration rate of 0.86 cu. ft./gal of sewage or greater exhibited significantly improved phosphorus removals as indicated by the low TSP residuals in the aeration tank effluent.

The hourly data from the four runs showed little variation. As a result, the daily data was averaged and plotted in Figures 10, 11, 12, and 13. Figure 10 indicates, that to maintain a DO of at least 2.0 mg/L in the aeration tank beyond the turnpoint, an air application rate of at least 0.86 cu. ft./gal. was required.

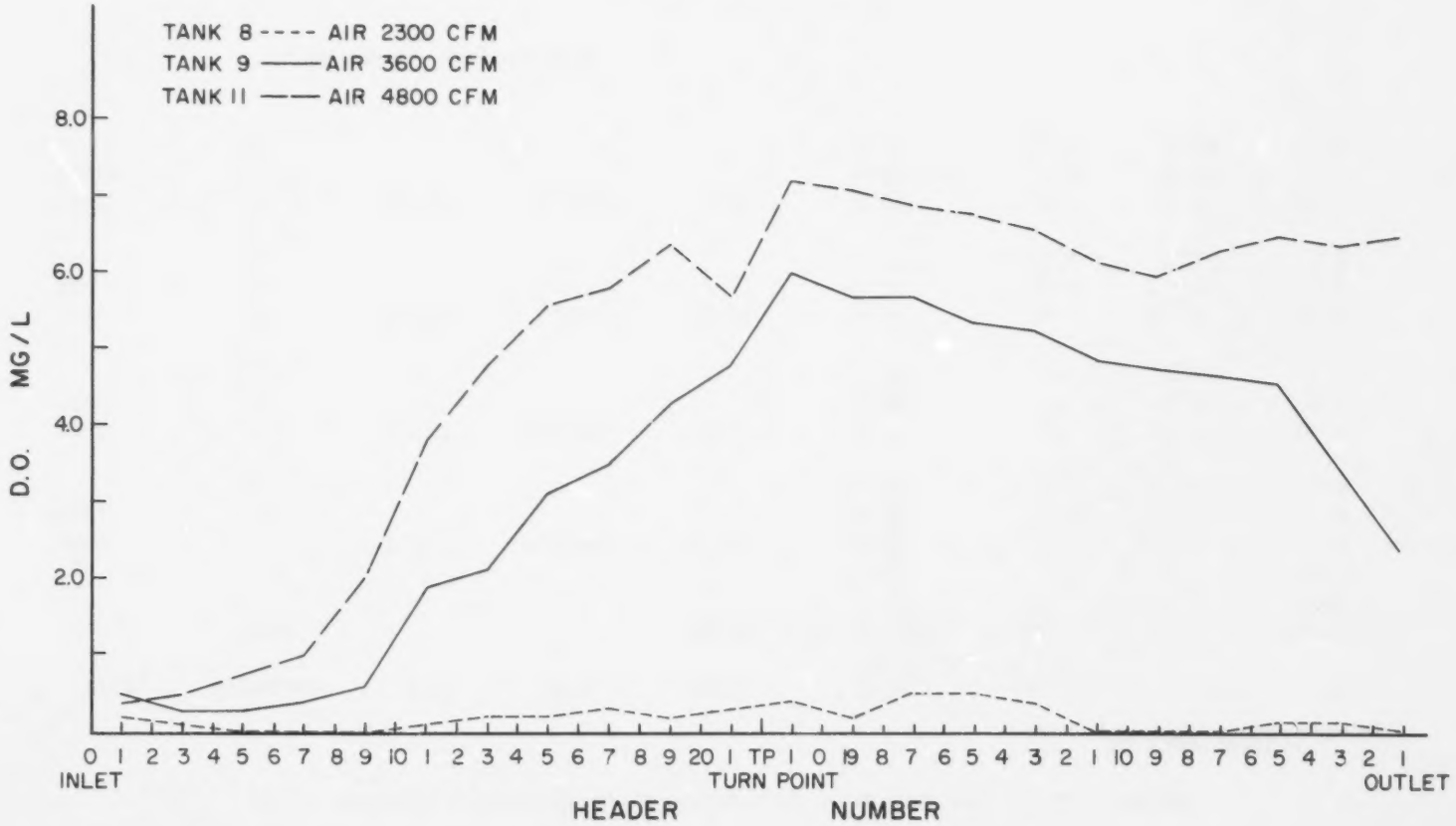


FIGURE 9 AERATION TANKS D.O. PROFILES (10-6-1969, 12:30 P.M.)

TABLE 11

DAILY PROCESS PARAMETER DATA (Detention time controlled to 6 hours)

Date	Aeration Tank	F/M	TP/M	MLSS mg/L	Air cu. ft./gal.	At Tank Outlet ML-DO mg/L	ML-TSP mg/L-P	ML Soluble BOD mg/l
10-6 Mon.	8	0.517	0.0349	2530	0.57	1.0	6.4	9.4
	9				0.86	6.0	0.34	4.4
	11				1.16	7.8	0.28	4.4
10-7 Tues	8	0.547	0.0196	2610	0.57	*	14.4	14.4
	9				0.86	*	0.24	5.4
	11				1.16	*	0.18	4.2
10-8 Wed.	8	0.635	0.0215	2770	0.57	0.5	11.5	15.4
	9				0.86	1.2	0.20	5.6
	11				1.16	3.5	0.16	5.8
10-9 Thurs.	8	0.457	0.0159	2910	0.57	0.5	9.7	14.0
	9				0.86	1.0	0.24	6.2
	11				1.16	2.5	0.24	5.4

* D. O. meter inoperative

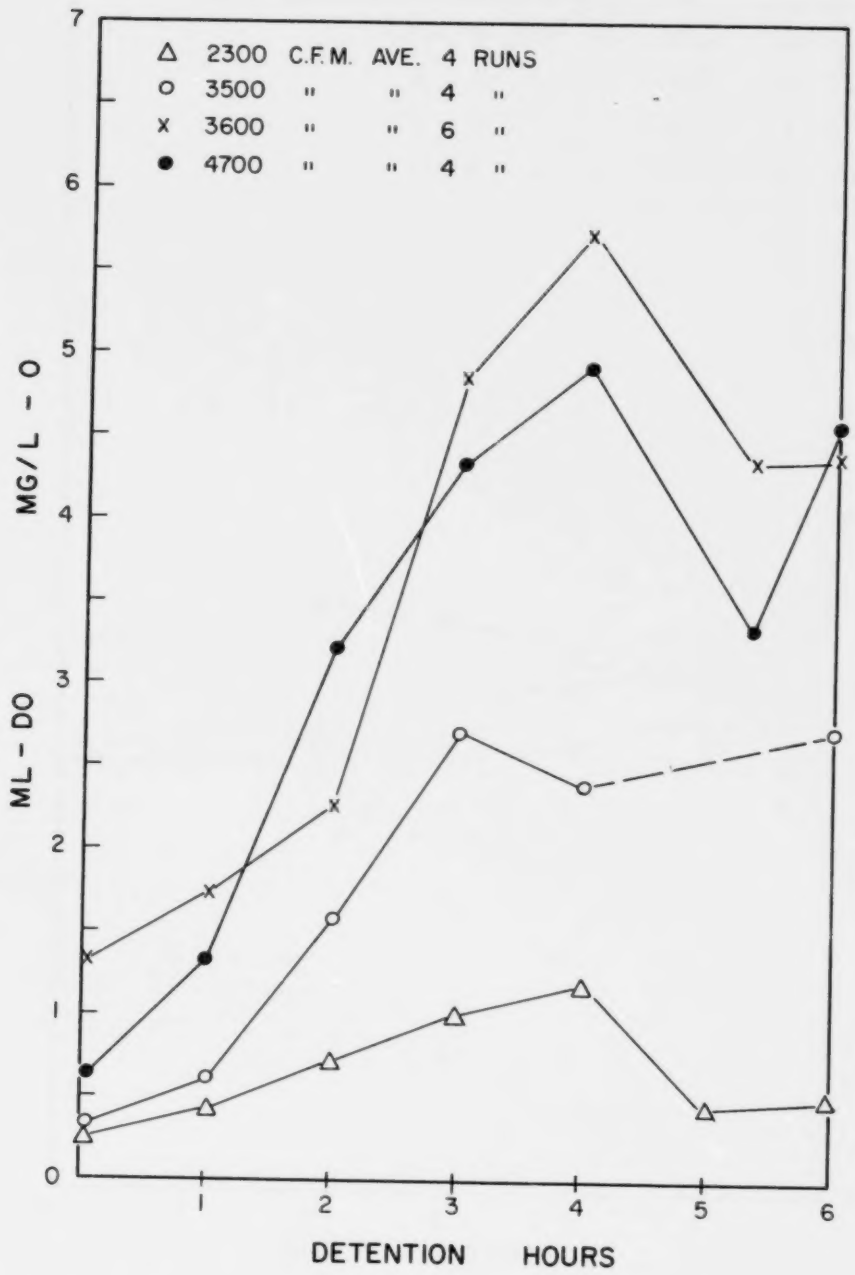


FIGURE 10 EFFECT OF AIR APPLICATION RATE ON ML-DO LEVEL

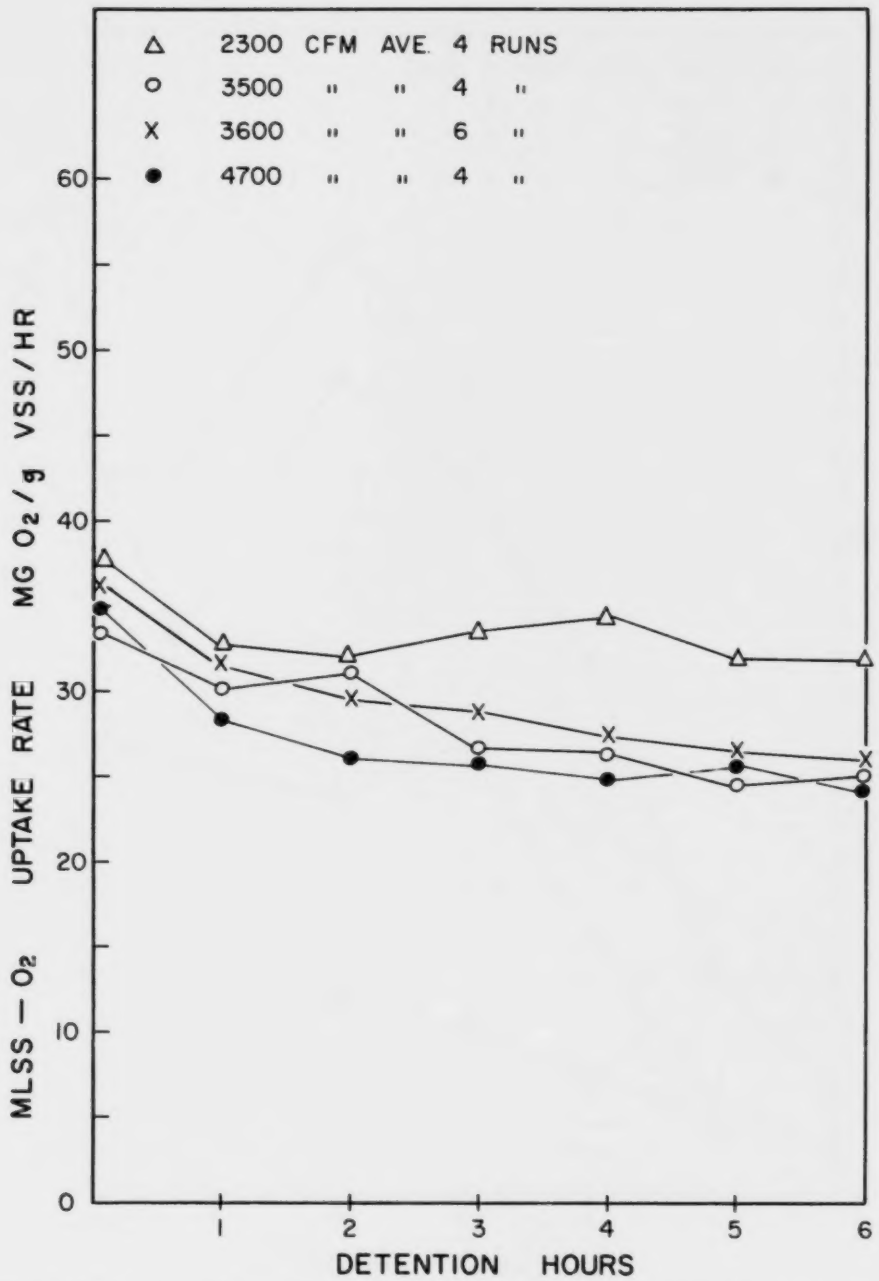


FIGURE 11 EFFECT OF AIR APPLICATION RATE ON MLSS — O_2 UPTAKE RATE

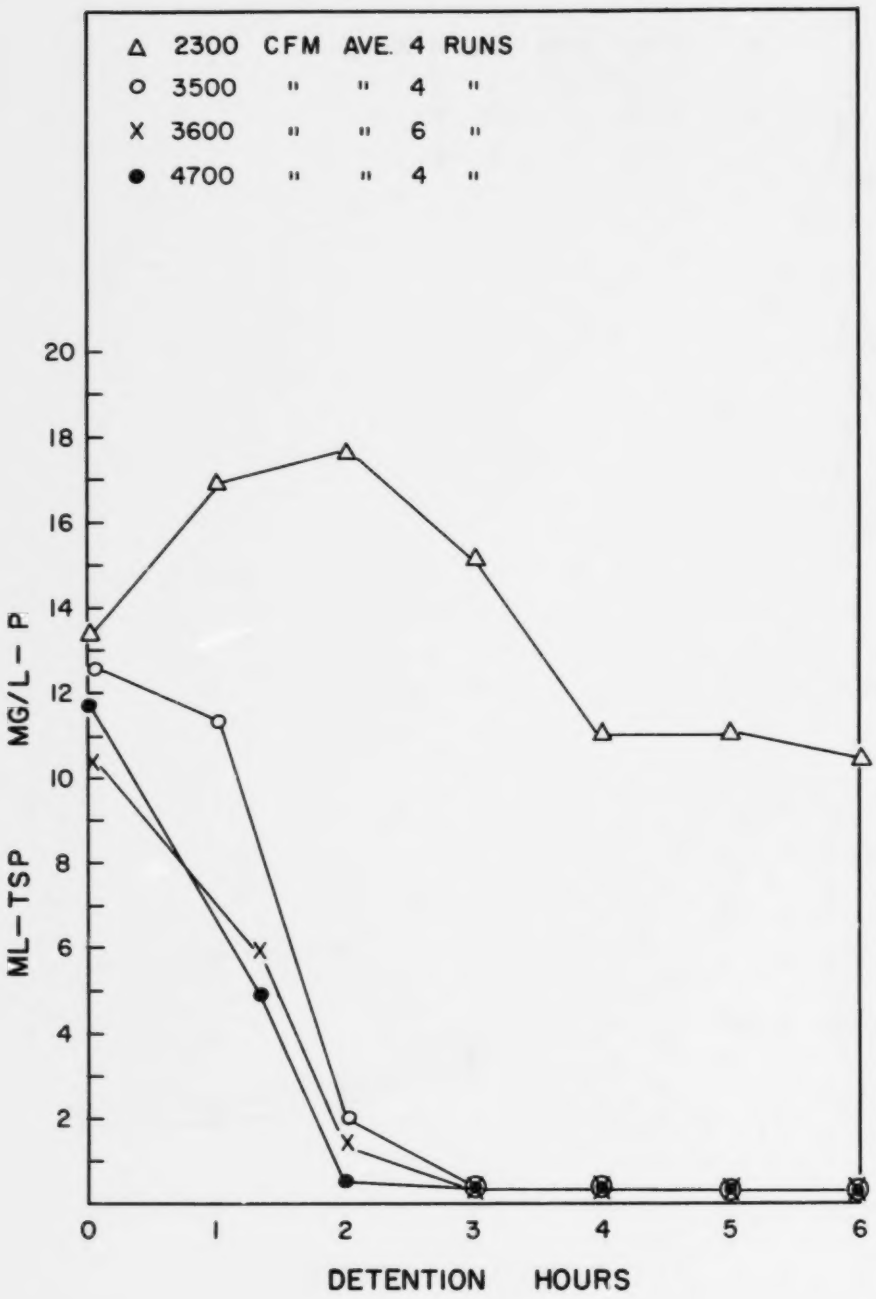


FIGURE 12 EFFECT OF AIR APPLICATION RATE ON ML-TSP LEVEL

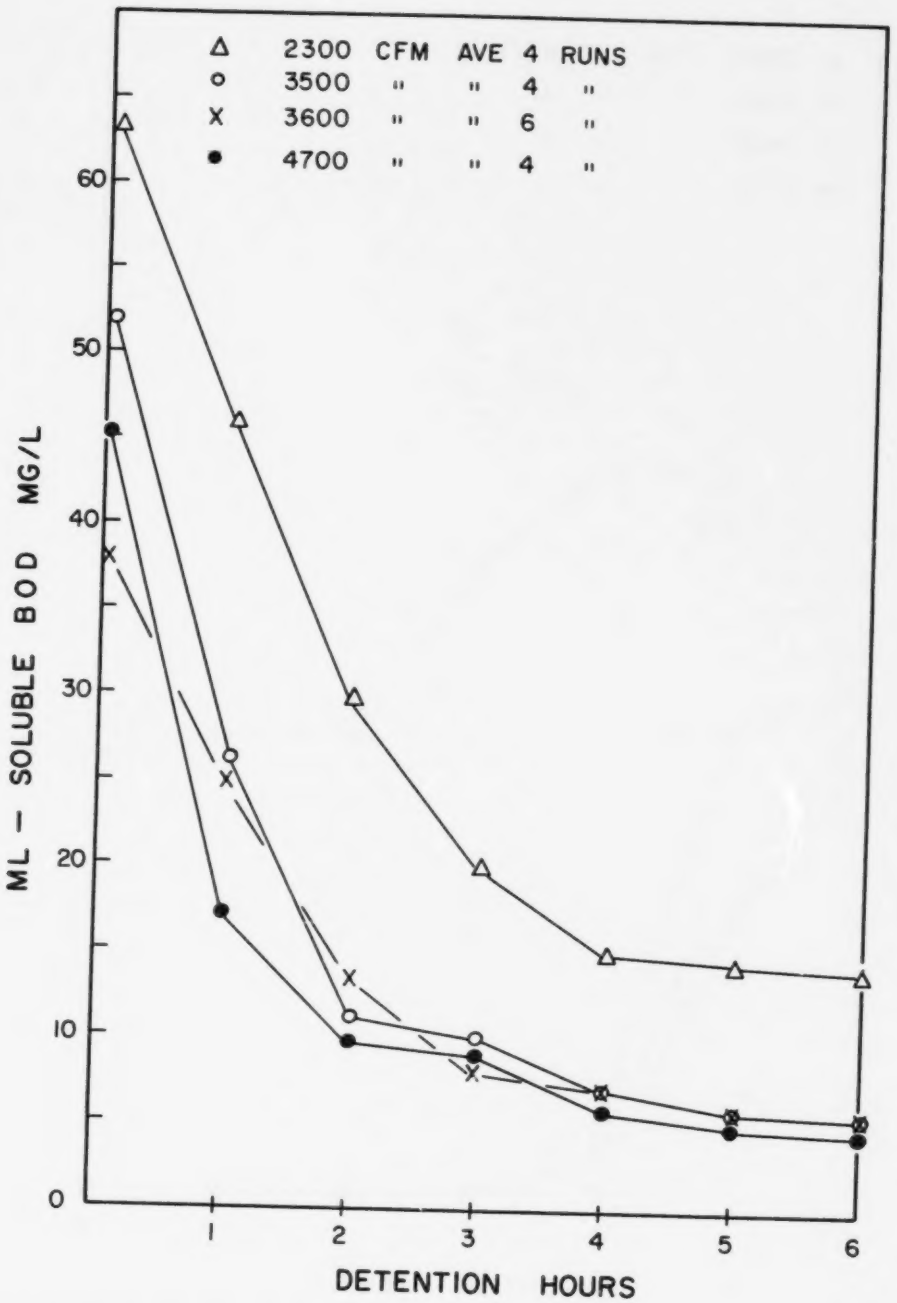


FIGURE 13 EFFECT OF AIR APPLICATION RATE ON ML-SOLUBLE BOD LEVEL

As plotted in Figure 11, MLSS-O_2 uptake rates observed in this study at 0-hour detention time in the aeration tank were about half of the values reported by Eckenfelder (37). This may be due to approximately 20 minutes aeration of the ML in the long feed channels prior to entrance of the ML into the aeration tanks.

TABLE 12

MLSS-O_2 UPTAKE RATE AFTER 6 HOURS AERATION

AIR APPLICATION RATES		mg O_2/gm VSS/hr.		
		AVERAGE	RANGE	
CFM	cu. ft./GAL.	(4 RUNS)	LOW	HIGH
2300	0.57	32.4	28.9	36.0
3500	0.86	25.1	22.3	27.1
4700	1.16	23.8	19.5	26.1

The above values in Table 12 compare favorably with those reported by Okum and Lynn (38) of 22 to 28 mg O_2/gm VSS/hr. At no time were the endogeneous oxygen uptake rates of 1.9 to 9.8 mg O_2/hr/1000 mg sludge as reported by Eckenfelder (37) observed. An examination of Figures 12 and 13 indicates that an aeration rate of 0.57 cu.ft./gal. of sewage was insufficient for soluble phosphorus removal but did not affect the BOD removals.

EVALUATION OF MLSS METABOLIC ACTIVITY BY GLUCOSE DEHYDROGENASE ASSAY

Observations of the daily process parameters data indicated that they are sufficient to explain why poor or good soluble phosphorus removal occurs in the Milwaukee activated sludge plants. Ford, Young and Eckenfelder, (39) investigated the use of a glucose dehydrogenase assay for evaluating the biological activity of sludges. It was then thought that if the removal of soluble phosphorus in the activated sludge process could be related to the biological activity of the MLSS, this additional information could probably explain the observed deviations.

In an aeration tank, the oxygen uptake rate of the MLSS decreases with increasing detention and air application rate (Refer to Figure 11). Thus, the metabolic or oxidative activity as represented by the MLSS-glucose dehydrogenase activity could be expected to decrease from the tank inlet to the tank outlet and perhaps coincide with the SOP being removed by the MLSS.

The data of Ford, et. al. (39) showed that the MLSS-glucose dehydrogenase activity within a sampling location exhibited a very large coefficient of variation (C.V.). They performed one hundred triplicate analyses on samples from three sampling locations and obtained C.V.'s of 31.6%, 24.5% and 23.8% respectively.

For this study to be worthwhile it was necessary to determine whether the large variation in MLSS-glucose dehydrogenase activity reported by Ford was caused by the assay itself or was caused by the samples that were taken from a specific sampling site. In this study, seven liter ML samples taken from the inlet, turnpoint and outlet of an aeration tank were each analyzed in triplicates for MLSS and MLVSS (Appendix B) and glucose dehydrogenase activity.

The standard deviation of the dehydrogenase assay was calculated from the grand average range of the range of triplicate analyses per sample (19 samples from each of three sampling sites) according to the procedure given by Natrella (40). The values used in this calculation were the range of triplicate determinations per sample as shown in Table 13.

TABLE 13

DEHYDROGENASE ASSAY VARIABILITY

(μM TPF/5 ml of ML)

SAMPLING SITE	RANGE OF TRIPLICATES			STANDARD DEVIATION
	AVERAGE	HIGH	LOW	
INLET	.032	.072	.013	.0189
TURNPOINT	.049	.097	.000	.0289
OUTLET	.050	.184	.000	.0295

The actual value from the assay used in calculating MLSS-glucose dehydrogenase activity for each sample was the average of the triplicate analyses for each sample. These values exhibited wide variations for the ML samples analyzed as shown in Table 14.

TABLE 14

DEHYDROGENASE ASSAY DATA

(μM TPF/5 ml of ML)

Sampling Site	Average	Range	
		High	Low
INLET	0.822	1.150	0.415
TURNPOINT	0.762	1.043	0.285
OUTLET	0.729	1.051	0.212

The comparison of data in Tables 13 and 14 indicated that the reproducibility of the assay was fairly good and that the wide variations in MLSS-glucose dehydrogenase activity was due to the samples which were taken within a sampling site for analyses.

The variability of the MLSS-dehydrogenase activity according to sample sources (same 19 runs) was also determined as shown in Table 15. The MLSS-dehydrogenase activity was expressed as μM TPF/mg MLVSS (μM Triphenylformazin produced/mg MLVSS).

TABLE 15

VARIABILITY OF ML - DEHYDROGENASE ACTIVITY AND MLVSS

AT DIFFERENT SAMPLE LOCATIONS

Aeration Tank Sample Location	ML-Dehydrogenase Activity			MLSS		MLVSS	
	Average μM TPF/mg MLVSS	Standard Deviation	% CV	Ave. mg/l	Ave. %VSS	Std. Dev.	% CV
Inlet	0.072	0.0149	20.7	3030	75.2	0.89	1.18
Turnpoint	0.068	0.0130	19.1	3160	74.3	0.89	1.20
Outlet	0.063	0.0141	22.4	3130	73.9	0.79	1.07
Average	———	———	20.7	———	———	———	1.15

Std. Dev. = Standard Deviation

The above data continued to show that the large variation in the glucose dehydrogenase activity within a sampling site was due to the variation from sample to sample. The CV of the MLSS-glucose dehydrogenase activity at different sample locations conform to those reported by Ford as shown in Table 16.

TABLE 16

COMPARISON OF COEFFICIENTS OF VARIATION (C.V.)

Milwaukee Data

Sample Location	% C.V.
Aeration Tank Inlet	20.7%
Aeration Tank Turnpoint	19.1%
Aeration Tank Outlet	22.4%
Average	20.7%

Ford's Data

Sample Location	% C.V.
Contract Tank	31.6%
Stabilization Tank (Sampling Point A*)	24.5%
Stabilization Tank (Sampling Point B*)	23.8%

*Sampling Location Not Specified in Reference (39)

The usage of the glucose dehydrogenase assay to evaluate the metabolic or oxidative activity of the MLSS in an activated sludge plant was found to be of little practical value as a large number of samples would have to be analyzed to provide significant

data. It should be noted that the data on the average did show that the MLSS-glucose dehydrogenase activity decreases with increasing detention time. (see Table 15).

Jones and Prasad (41) made a detailed study on the use of tetrazolium salts as a measure of sludge activity. They concluded that, "The TTC dehydrogenase test in mixed cultures and complex substrates at best can be considered as a gross measurement of activity. The interpretation of the data should be approached with caution particularly if it is being used as a research tool."

X-RAY DIFFRACTION STUDIES OF SEWAGE SUSPENDED SOLIDS AND WASTE SLUDGE SOLIDS

In the literature, the removal of sewage phosphorus by the activated sludge process has been attributed to cationic precipitation or biological uptake, or a combination of both. Therefore, a knowledge of the mechanism or mechanisms prevailing would not only enable us to obtain a better understanding of the phosphorus removal process but also to develop concepts for the improvement of phosphorus removal in the activated sludge system. Many cations (iron, aluminum, calcium and magnesium) have been successfully added to aeration units by many investigators to enhance the removal of soluble phosphorus. If a qualitative and quantitative procedure to determine the presence of these inorganic phosphate compounds in sewage suspended solids and waste sludge solids were available, the mechanism of phosphorus removal by the activated sludge process could be better explained.

Accordingly, staff members of Marquette University, Milwaukee were consulted on the use of X-Ray diffraction analysis to determine if these inorganic phosphate compounds were present in the sewage suspended solids and waste sludge solids.

The preliminary X-Ray diffraction studies (42, 43, 44) revealed that a crystal-like compound in the 103°C oven dried RS gave an X-Ray diffraction pattern very similar to that of Iron (III) orthophosphate ($FePO_4$). This observation could not be confirmed and studied further because of the appearance of too many background lines in the X-Ray diffraction patterns obtained in the subsequent studies due to amorphous material in the sludge. The sludge samples were then heated at different temperatures to see if the background darkness could be decreased. Heat treatment of the samples (500°C to 600°C) decreased the background darkening considerably, but this high temperature heat treatment changed the nature of the compound formed and resulted in a homogeneous mass.

Freeze drying of the sample was tried. This did not help in decreasing the background but did result in a heterogenous mass containing some black crystals. These black crystals were separated and found to give patterns similar to vivianite, $Fe_3(PO_4)_2 \cdot 8H_2O$. Further research will be conducted in an attempt to purify and evaluate the concentration of these black crystals. Magnetic separation techniques are currently under study and show promise of success. These X-Ray studies are being continued under Project Grant Number 11010, FLQ, "Phosphorus Removal With Pickle Liquor In A 115 MGD Activated Sludge Plant".

CATIONIC REMOVAL OF PHOSPHORUS FROM SEWAGE

A number of investigators have studied the ability of certain cations (Fe^{+++}, Fe^{++}, Al^{+++}, Ca^{++}, and Mg^{++}) to enhance the soluble phosphorus removals in the activated sludge process. Very little information is available in the literature on the concentrations of these soluble cations in sewage and their effect on sewage phosphorus removal. Studies were undertaken to assess the role of Fe, Al, Ca and Mg ions, normally present in Milwaukee sewage, in the removal of SOP by the two Milwaukee activated sludge plants.

Currently, it was assumed that the insoluble cations (i.e., the cations present in the sewage suspended solids) are tied up possibly as $Fe(OH)_3$ and are not available for reaction with SOP to form insoluble phosphate compounds during the activated sludge process. A comparison of the influent and of the effluent soluble cation concentrations would indicate if these cations were removed in the activated sludge process. It was hypothesized that if a decrease in the soluble cation concentration was observed, this decrease was due to the formation of an insoluble phosphate compound through its reaction with SOP.

The cation analyses were performed on the unneutralized ternary acid digestate of 24 hour composite samples of screened sewage, EP and WP effluents by atomic absorption. The initial work was carried out using the 24 hour composite samples to determine if there was a significant change in the soluble cations concentrations on a daily basis during July of 1969. The daily data exhibited marked fluctuations because of the limited experience on the atomic absorption unit by laboratory personnel. Therefore, only monthly averages are presented in Table 17

TABLE 17

AVERAGE CATION CONCENTRATIONS (mg/L) FOR JULY, 1969

	TOTAL CATION CONCENTRATIONS			TOTAL SOLUBLE CATION CONCENTRATIONS		
	Screened	Effluent		Screened	Effluent	
Cation	Sewage	WP	EP	Sewage	WP	EP
Fe^{++} & Fe^{+++}	5.00*	0.71	0.59	0.55	0.32	0.29
Al^{+++}	2.00	0.53	0.41	0.44	0.33	0.27
Ca^{++}	52.4	48.8	47.9	48.6	47.7	47.2
Mg^{++}	31.8	30.7	30.2	30.4	30.5	30.3

*Partly influenced by filtrate from vacuum filters

The above data showed that both activated sludge plants removed very little of the soluble cations of Fe, Al, Ca and Mg. Based on this data, the removal of SOP in the Milwaukee activated sludge plants by the sewage soluble cations would be very insignificant. From the above data one could assume that the cationic fixation of soluble phosphorus probably takes place in the sewage prior to its reaching the plant. The consistently low amount of total soluble iron in Milwaukee sewage (usually $<$ 1.0 mg/l-Fe) may be due to the low solubility of the iron phosphate compound present in the sewage suspended solids.

The initial X-Ray diffraction studies on the 103°C dried sludge samples indicated that one of the insoluble cation phosphate compounds was possibly $FePO_4$ which in the wet sludge may be present as $FePO_4 \cdot 2H_2O$ or $FePO_4 \cdot 4H_2O$. The theoretical solubility product of $FePO_4 \cdot 2H_2O$ is 1×10^{-33} in distilled water according to Chang and Jackson (45). The solubility product of $FePO_4 \cdot 2H_2O$ in sewage was calculated from the observed data and was found to average 6.7×10^{-22} at pH 8.0. This higher value would be expected since sewage contains substances, such as detergents, polyphosphates, chelating agents, salts and other unknown compounds which could increase the solubility of $FePO_4 \cdot 2H_2O$ in sewage. The above assumptions are reasonable because the calculated solubility product agreed with that reported by Galal-Grochev and Stumm (46) of 1×10^{-23} at a pH greater than 7.0 at 25°C for $FePO_4$.

Since the activated sludge process removes polyphosphates, surfactants, etc., from sewage the solubility product of ferric phosphate would be expected to decrease. The calculated solubility product of $FePO_4 \cdot 2H_2O$ in ML after 6 hours aeration was found to decrease to an average of 1.3×10^{-25} at pH 7.0.

EFFECT OF IRON ADDITION TO AN AERATION TANK ON SOLUBLE PHOSPHORUS REMOVAL

During June and July of 1969 the TSP and SOP removal efficiencies for both plants dropped from an average of 80% to an average of 40%. The period of reduced removals coincided with the breweries shutdown which was discussed in a previous section. This was an opportune time to begin a cationic addition experiment, since this period of extremely reduced SOP and TSP removals could provide more reliable and significant data on the cationic removal of soluble phosphorus.

This phase of the study was a cooperative venture with the A. O. Smith Corporation of Milwaukee, who supplied the cationic compound, ferrous sulfate as waste pickle liquor needed for the addition of iron to the ML. The industrial waste used contained from 0.4 to 1.0 pound of iron per gallon and usually had a pH of about 1.0. Neutralized and unneutralized pickle liquor were used in this study.

The initial work was limited to the addition of iron to one of the aeration tanks of the EP. This approach was taken to determine the effective iron dose, the desired addition site, and the material handling problems associated with the pickle liquor addition. We were also interested in determining if this waste product would have any detrimental influence on the activated sludge process or on the air diffuser plates.

The waste pickle liquor was first added to the aeration tank at the turning point, providing 3 hours detention, and then at the inlet, providing 6 hours detention. The ML flows to the aeration tanks were held at 7.0 to 7.5 mgd to provide about 6 hours detention, and the air application rate was maintained at approximately 3200 cfm. The iron was added 24 hours'/day from Monday to Friday and the pickle liquor addition rate was manually controlled. This study was conducted for two periods of three weeks each. An adjacent aeration tank with the same ML flow and aeration pattern was used as a control. The experimental and control tanks ML were sampled at the inlet, turnpoint and outlet every 2 to 3 hours continuously. The ML samples were analyzed for total iron, total soluble iron, TP, TSP, MLSS, pH, and ML-SDI, and ML-DO at the tank outlets.

The iron dosing rates maintained were approximately 7.5, 15, and 30 mg/L-Fe based on the hourly ML flow. The averages of the bihourly and trihourly data by week are presented in Table 18. The data such as given in Table 18 showed that the addition of ferrous iron in the form of waste pickle liquor was very effective in the reduction of ML-TSP. Actual iron dosing rates of 11.0 to 27.4 mg/L-Fe (based on ML flow) resulted in average ML-TSP residuals between 0.23 to 0.49 mg/L-P and reduced the inlet ML-TSP levels (3.5 to 8.5 mg/L) by 77.3 to 94.2%

TABLE 18

EFFECT OF IRON DOSAGE ON ML-TSP LEVEL

Run No	Date 1969	Iron Addition Dosage (1) mg/L-Fe	Site	Average ML-TSP mg/L-P Inlet (2)	Outlet (3) Exptl. Tank	Outlet (3) Control Tank	% Reduction ML-TSP Exptl. Tank	% Reduction ML-TSP Control Tank
1	7/1 to 7/3	11.0	TP (4)	3.5	0.46	1.9	86.9	45.7
2	7/8 to 7/11	6.8	TP	4.85	1.1	2.8	77.3	42.3
		27.4	TP	4.65	0.46	2.5	90.1	46.3
3	7/15 to 7/18	30.0 (5) past	TP (6)	4.1	0.31	2.0	92.4	51.2
		15.0 (5) past	TP	2.8	0.23	0.76	91.8	72.9
4	8/4 to 8/8	13.3	Inlet	5.4	0.40	0.88	92.6	83.7
5	8/11 to 8/15	15.5	Inlet	6.9	0.45	1.2	93.5	82.6
6	8/18 to 8/22	17.0	Inlet	8.5	0.49	1.1	94.2	87.1

(1) Dosage based on Pickle Liquor iron analyses
(2) Average of experimental and control tanks inlet ML-TSP
(3) Outlet ML samples (6 hours detention)
(4) TP = tank turnpoint and is 1/2 of tank length
(5) In run 3 these dosages are estimates
(6) Past TP (2 hours detention)

All three iron addition sites (2,3 and 6 hours detention) were found to be effective, provided there was sufficient ML-DO. The role of ML-DO level on the effectiveness of ferrous iron in TSP removal was observed in run 6 and a typical observation at an aeration rate of 3600 cfm. is given below in Table 19

TABLE 19

RUN 6 OBSERVATION DATA

	Turnpoint		Outlet	
	D.O. MG/L	ML-TSP MG/L	D.O. MG/L	ML-TSP MG/L
Control Tank	2.7	1.1	5.0	0.35
Experimental Tank	0.5	5.2	6.6	0.22

In Table 18 it can be seen that the average removal of TSP by the MLSS in the control tank was much better in runs 4, 5 and 6 than in runs 1, 2 and 3, even though the inlet average ML-TSP levels were much higher in runs 4, 5 and 6 compared to the early runs. This difference is attributed to the effect of the breweries waste water on the Milwaukee plants. First, the initial iron addition runs (7-1-69 to 7-18-69) were carried out during the breweries shutdown period (6-9-69 to 7-15-69) when the daily soluble phosphorus removals averaged less than 40%. In the second set of runs (8-4-69 to 8-22-69) the breweries were back in operation and the daily soluble phosphorus removals improved to an average of greater than 80%. The results indicated that the addition of ferrous iron as pickle liquor to ML was effective in maintaining low residuals of TSP in ML after 6 hours of aeration.

Added soluble ferrous sulfate as pickle liquor was rapidly incorporated into the MLSS. This was found by the analysis of ML samples for total soluble iron taken at ten foot interval sampling points from the iron addition site at the tank turnpoint as shown in Table 20.

TABLE 20

REDUCTION OF SOLUBLE IRON CONCENTRATION IN AN AERATION TANK

(Iron * was added as waste pickle liquor at the aeration tank turnpoint)

DISTANCE FROM TANK TURNPOINT (FEET)	TOTAL SOLUBLE IRON FOUND IN THE ML (mg/L-Fe)
10	1.14
20	1.14
30	0.58
40	0.50
50	0.56
60	0.58
70	0.44
80	0.44
90	0.43

* Iron dosing rate 7.5 mg/L - Fe based on ML flow.

The average ML total soluble iron concentrations at the inlets and outlets were practically the same, 0.23 to 0.39 mg/L-Fe respectively during the 6 test runs in the experimental tank.

The iron added, as obtained by calculation, from the pickle liquor data compared favorably with the average total iron found in the inlet and outlet MLSS as shown in Table 21.

The clarifier detention times are approximately 2 to 3.5 hours. During this time period it has been previously shown that soluble phosphorus is released from the solids. Ten iron and phosphorus tests were performed in the laboratory with the samples of ML from the control and experimental tanks outlet and then the release of phosphorus and iron after two hours detention was determined. The average results of the ten test runs as given in Table 22, indicate that in a period of 2 hours the MLSS treated with iron release less TSP than the untreated MLSS from control tanks and that the iron treated MLSS released more soluble iron than the untreated MLSS.

TABLE 21

AVERAGE IRON RECOVERIES

Run No.	Planned Iron Addition Rates		Calculated Iron Addition Rates	Actual Iron Found In the Outlet MLSS mg/L-Fe		Observed Average Recovery of Added Iron Dose
	gpm	mg/L-Fe	mg/L-Fe	Exptl Tank	Control Tank	mg/L-Fe
1	1.0	15	11.0	70.6	59.2	11.4
2	0.5	7.5	6.8	55.0	49.9	5.1
	2.0	30	27.4	80.5	56.7	23.8
3	2.0	30(a)		84.3	60.8	23.5
	1.0	15(a)		75.1	60.0	15.1
4	1.0	15	13.3	68.5	55.9	12.6
	0.5(b)	15	13.2			
5	1.0	15	15.5	78.1	59.8	19.0(c)
6	1.0	15	17.0	90.4	74.4	16.0

(a) Iron dosing rate estimated from pickle liquor specific gravity.

(b) Concentrate (undiluted pickle liquor)

(c) The large difference in run 5 may be partly due to inadequate manual control of pickle liquor flow.

TABLE 22

SOLUBLE IRON AND TSP RELEASE BY MLSS
(average of 10 tests)

	Control Tank		Experimental Tank	
Detention Hours	0 hour	2 hours	0 hour	2 hours
Total soluble Iron mg/L-Fe	0.21	0.30	0.27	0.71
TSP mg/L-P	1.64	3.01	0.29	1.15

In general, the neutralized and the unneutralized waste pickle liquor were observed to have no detrimental effect on the activated sludge process. This was shown by the experimental and control tanks ML having similar pH's, MLSS-O_2 uptake rates, SDI values. Microscopic examinations showed no changes in the biota. In this limited study no apparent clogging of aeration tank diffuser plates was observed.

PLANT SCALE IRON ADDITION STUDY

This was a feasibility study of plant scale iron addition for improved soluble phosphorus removal during a two week period. The EP was used as the experimental plant and the WP as the control.

The iron was added in the form of ferrous sulfate as unneutralized pickle liquor, a waste product which was supplied by the A. O. Smith Corp. Milwaukee, in a cooperative venture. The A. O. Smith Corp. also provided personnel to monitor the pickle liquor iron concentrations and to control the iron dosing rate 24 hours a day.

The pickle liquor was added to the EP sewage feed channel 65 feet upstream from the EP RS feed pipe. The ferrous iron concentration in the pickle liquor was determined by titration with 0.10N potassium dichromate. The iron addition rate was then based on the pickle liquor iron content and the hourly ML flow rate. A dosing rate of about 15 mg/L-Fe based on the ML flow was used from 11/3 to 11/7 (24 hours/day for 4-1/3 days) during which a total of 110,898 gallons of pickle liquor (74,300 pounds of iron) was added to the ML. From 11/10 to 11/14 (24 hours/day for 4-1/3 days), 52,345 gallons (37,200 pounds of iron) of pickle liquor was added to ML for a dosing rate of about 7.5 mg/L-Fe. The sampling procedures and the analytical methods used were as described in previous sections. The data from the 24 hour WP and EP composite effluent samples do not readily show the effectiveness of the added iron in reducing the effluent residual SOP as shown in Table 23. However, a comparison of the SOP content of the sewage and EP effluent bihourly composite samples (Figure 14) illustrates very dramatically that a 15 mg/L-Fe dosing rate consistently produced an effluent SOP residual of 0.05 mg/L-P for 4-1/3 days. The 7.5 mg/L-Fe dosing rate was not very effective as shown in Figure 14.

In the previous section it was found that in an aeration tank the added soluble iron was rapidly removed, and did not appear to significantly increase the ML total soluble iron content. This was also observed during this study in the daily data from both plant effluents. The total soluble iron in the plant effluent averaged 0.34 mg/L-Fe for the WP and 0.31 mg/L-Fe for the EP.

Plotted in Figure 15 are the WP and the EP SDI and MLSS shift averages on a daily basis. The plots show that during this study period the ML settleability fluctuated with a weekly cycle, improving on Sunday, Monday and Tuesday and deteriorating steadily from Wednesday to Saturday for both the plants. The plot also shows that an iron dosing rate of 15 mg/L-Fe was more effective than the 7.5 mg/L-Fe dosing rate in improving the settleability (SDI)

TABLE 23

EFFLUENT SOP mg/L-P

	No Iron Addition			Iron Addition						No Iron Addition		
	10/27/69 to 11/2/69			15 mg/L-Fe 11/3/69 to 11/9/69			7.5 mg/L-Fe 11/10/69 to 11/16/69			11/17/69 to 11/23/69		
	Date	WP	EP	Date	WP	EP	Date	WP	EP	Date	WP	EP
Monday	10-27	0.14	0.15	11-3	0.17	0.07	11-10	0.46	0.41	11-17	0.20	1.6
Tuesday	10-28	0.16	0.21	11-4	0.10	0.05	11-11	0.59	0.12	11-18	0.31	0.75
Wednesday	10-29	0.45	0.46	11-5	0.19	0.05	11-12	0.60	0.22	11-19	0.21	0.58
Thursday	10-30	0.45	0.32	11-6	0.53	0.05	11-13	0.70	0.27	11-20	0.30	0.52
Friday	10-31	0.51	0.25	11-7	0.82	0.06	11-14	0.99	0.44	11-21	0.53	0.70
Saturday	11-1	0.13	0.14	11-8	0.31	0.05	11-15	0.27	0.19	11-22	0.45	0.31
Sunday	11-2	0.10	0.11	11-9	0.10	0.18	11-16	0.13	0.47	11-23	0.23	0.41

Note: Iron added only to the East Plant

Dosing Rate: 15 mg/L-Fe; 7 A.M. - 11/3/69 to 3:30 P.M. on 11/7/69

7.5 mg/L-Fe; 7 A.M. - 11/10/69 to 1:05 P.M. on 11/14/69

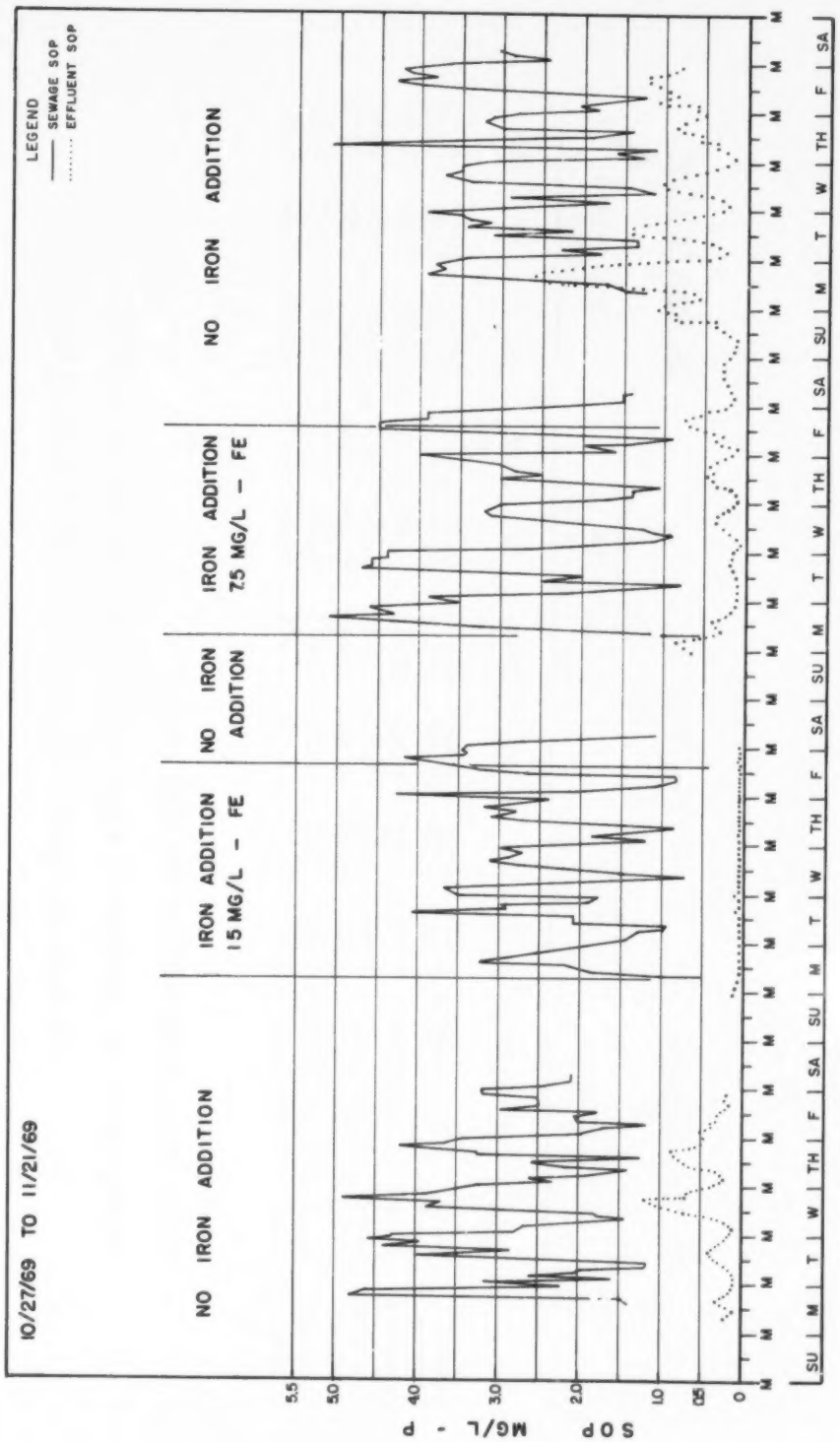


FIGURE 14 EFFECT OF IRON ADDITION ON EAST PLANT RESIDUAL SOP

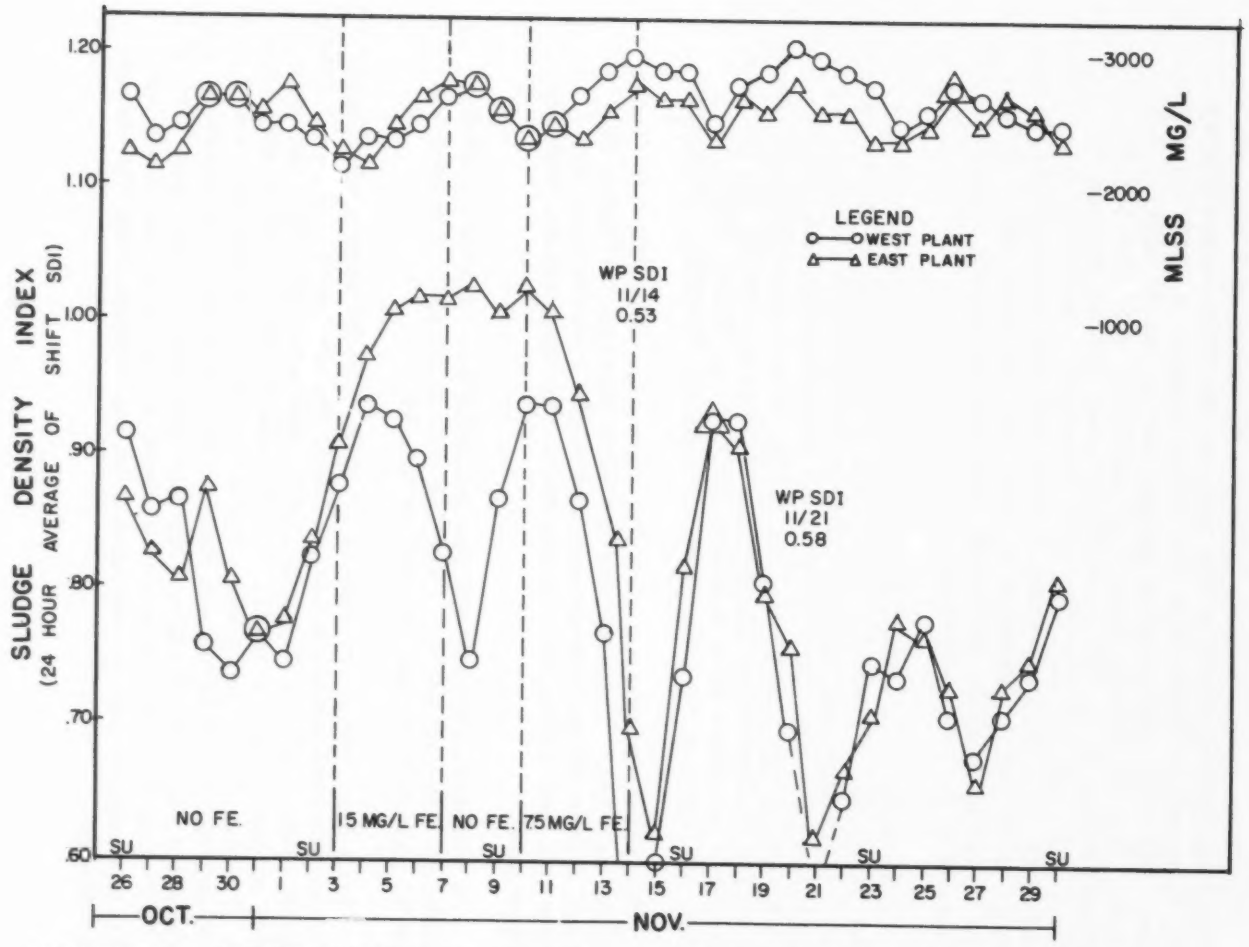


FIGURE 15 COMPARISON OF EAST & WEST PLANT SDI'S 1969

of the EP MLSS when compared to that of the WP MLSS. This was probably due to the iron accumulation in the MLSS which increased the density of EP MLSS.

The accumulation of added iron in the East Plant Return Sludge with time is plotted in Figure 16. The data was obtained from RS samples taken continuously at intervals of 2 hours.

The first iron addition (15 mg/L-Fe) began at 7 A.M. on 11/3/69 and the accumulation of the iron in the RSSS (approximately 2.5%) was observed to begin with the 4 P.M. sample on 11/3/69. From this point, the iron continued to accumulate in the RS until 8 A.M. on Thursday, 11/6/69 (64 hours of iron addition) and then the RS iron content stayed at a fairly constant level (at an average of 6.01%) until midnight of 11/7/69 (next 40 hours). This indicated that an equilibrium condition was reached when the iron wasting rate (i.e., the iron in EP-WS) was equivalent to the iron addition rate. From 4 A.M. on Saturday 11/8/69 the EP-RS iron content slowly decreased due to the cessation of iron addition.

The second iron addition (7.5 mg/L-Fe) was started at 7 A.M. on Monday 11/10/69. Figure 16 shows that at this iron addition rate the iron did not show any further buildup in the EP-RS (average 5.26%). This indicated that the equilibrium iron concentration was reached for these iron dosing and sludge wasting rates. After iron addition was stopped at 1 P.M. on Friday 11/14/69, the RS iron content was observed to continually decrease from 5.26% at 10 P.M. on Friday until it approached the initial RS iron level of 2.5% on Thursday, 11/20/69.

The total phosphorus contents were also determined on these bihourly RS samples. These values are also plotted in Figure 16. A comparison of the RS phosphorus and iron plots reveals that the phosphorus did not accumulate in the RS to the same extent that the iron accumulated.

It was anticipated that the accumulation of iron in EP-RS would increase its ash content, and the effect of the increased ash would be to reduce nitrogen content of the RS.

Each day, one liter sample of WP and EP-RS were centrifuged and the concentrated solids dried at 104°C for 24 hours. Ash and Total Kjeldahl Nitrogen (AOAC-2.042 and 2.043, reference 36) analyses were performed on the dried material. In Figures 17 and 18 are plotted the results of these daily analyses. These figures show that as iron addition continued the EP-RS ash content progressively increased as the iron was added, and the EP-RS ash content was much higher than that of the WP-RS. When iron addition was stopped on 11/14/69 the EP-RS ash content decreased as the accumulated iron was removed from the system as waste sludge.

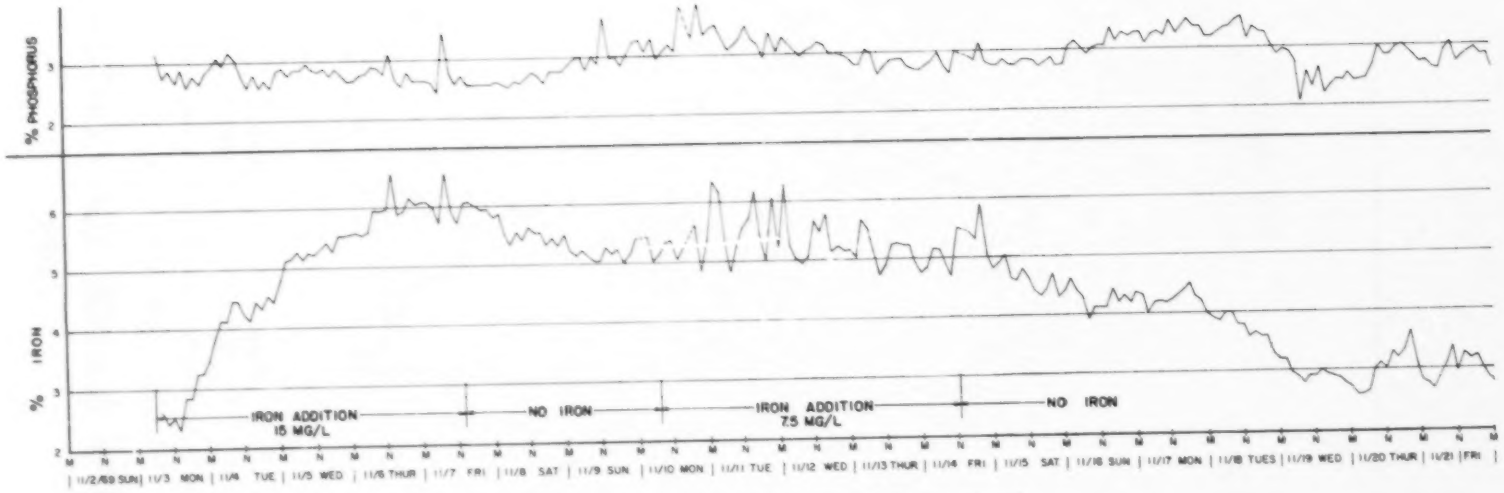


FIGURE 16 ACCUMULATION OF IRON IN EP-RS
1969

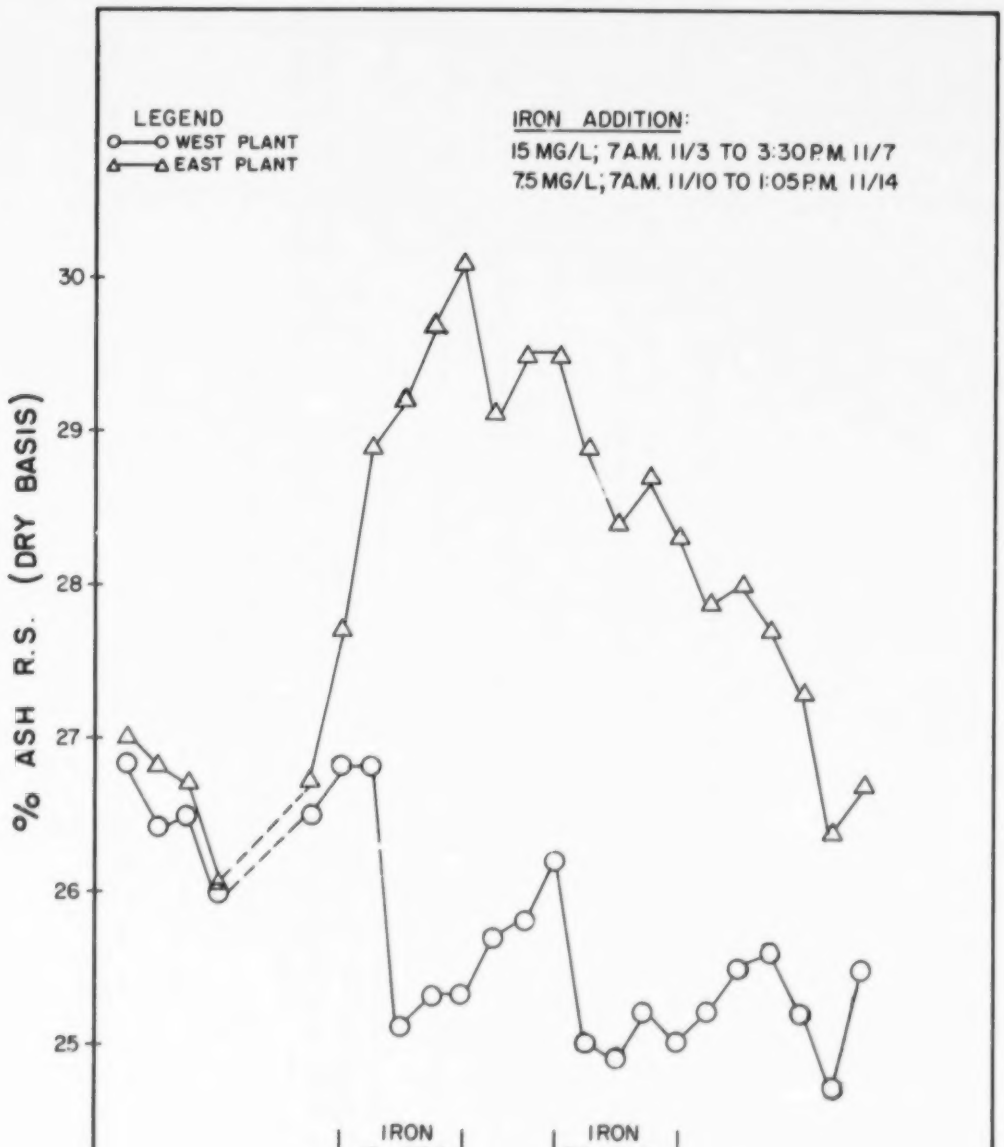


FIGURE 17 RETURN SLUDGE ASH CONTENT (DRY BASIS)
1969

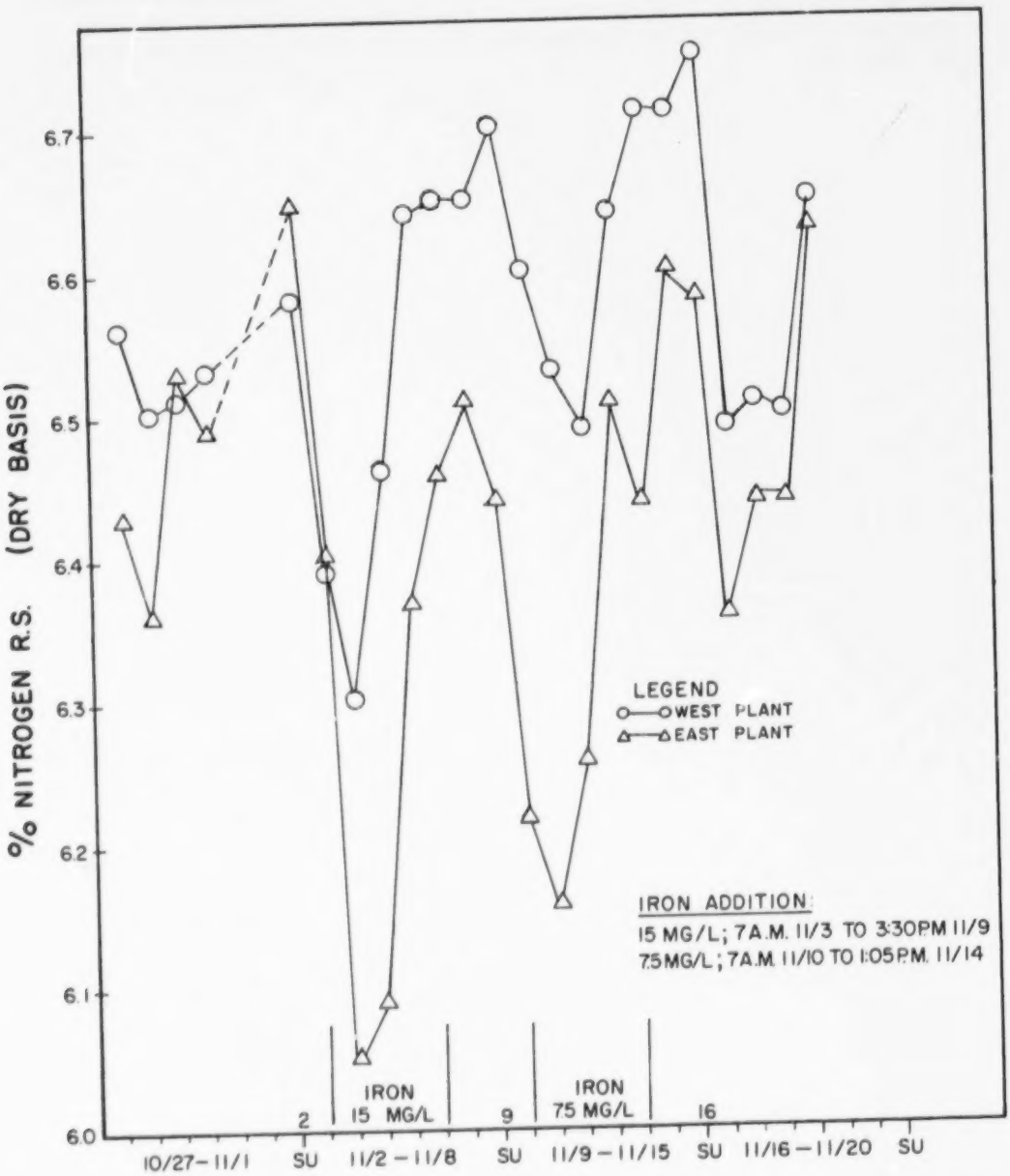


FIGURE 18 RETURN SLUDGE NITROGEN CONTENT (DRY BASIS)

1969

The effect of the increased ash content was to reduce the EP-RS nitrogen content as shown in Figure 18. The magnitude of the effect of ash content on the nitrogen content of this waste sludge can be obtained by a comparison of the average values of ash and nitrogen contents of RS during the iron addition periods as shown in Table 24.

TABLE 24

AVERAGE RETURN SLUDGE COMPOSITION

Iron Addition

	% Ash			% Nitrogen		
	WP	EP	Difference	WP	EP	Difference
15 mg/L						
11/3 to 11/7	25.9	29.1	3.2	6.49	6.27	0.21
% N based on VSS				(8.76)	(8.85)	(0.09)
7.5 mg/L						
11/10 to 11/4	25.2	28.8	3.6	6.59	6.32	0.27
% N based on VSS				(8.82)	(8.87)	(0.05)

SECTION VII

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SECTION VIII

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SECTION IX

PHOSPHORUS NOMENCLATURE AND ABBREVIATION'S GLOSSARY

PHOSPHORUS NOMENCLATURE

1. Total Phosphorus (TP).
   All the phosphorus present in sample (whether in the soluble or insoluble state and present as ortho, poly, organic, etc., phosphorus compounds) which is converted by ternary acid digestion to soluble ortho-phosphate.

2. Soluble Ortho - Phosphate (SOP).
   All phosphorus measured by direct colorimetric analysis of sample filtrate. (Angel Reeve Glass Fiber Pad No. 934AB).

3. Total Soluble Phosphorus (TSP).
   All the phosphorus compounds in the sample filtrate converted by ternary acid digestion to ortho-phosphate.

4. Suspended Solids Phosphorus (SS-P).
   Represents the phosphorus present in the sample suspended solids. (SS-P = TP - TSP).

ABBREVIATIONS GLOSSARY

1. BOD - five day biochemical oxygen demand.

2. BOD_R/TSP_R - ratio of BOD removed/day to TSP removed/day.

3. CV - coefficient of variation (standard deviation divided by the average, multiplied by 100).

4. CFM - cubic feet per minute.

5. COD - chemical oxygen demand.

6. DO - dissolved oxygen.

7. EP - East Plant.

8. EPML - East Plant mixed liquor.

9. EPRS - East Plant return sludge.

10. EPWS - East Plant waste sludge.

11. F/M - (Ratio of food to microorganisms) /Day.

$$\frac{\#BOD/DAY}{\#MLVSS \text{ in the Aeration Capacity}}$$

12. MGD - million gallons/day.

13. ML - mixed liquor.

14. ML-DO - mixed liquor dissolved oxygen.

15. ML-SDI - mixed liquor sludge density index.

16. MLSS - mixed liquor suspended solids.

17. MLSS-O_2 - mixed liquor oxygen uptake rate. mg O_2/mg VSS/hour).

18. MLVSS - mixed liquor volatile suspended solids.

19. N - nitrogen.

20. P - phosphorus.

21. RS - return sludge.

22. RSSS - return sludge suspended solids.

23. SOP - soluble ortho-phosphate.

24. SS - suspended solids.

25. TP - total phosphorus.

26. TSP - total soluble phosphorus

27. TP/M - (ratio of total phosphorus to Microorganisms)/Day.

$$\frac{\#TP/DAY}{\#MLVSS \text{ in the Aeration Capacity}}$$

28. µM TPF/5 mls of ML - micro-moles of triphenylformazin/ 5mls of mixed liquor.

29. VSS - volatile suspended solids.

30. WP - West Plant.

31. WS - waste sludge.

SECTION X

APPENDIX A

PHOSPHORUS DETERMINATION WITH TECHNICON AUTOANALYZER

Sample Preparation

A. Total Phosphorus

1. Pipette unfiltered sample into a 100 ml. volumetric flask (20 mls effluent, 5 mls for sewage).

2. Add 5 mls of Ternary Acid Mixture and 3 glass beads.

3. Heat on hot plate to dense fumes of perchloric acid, plus 5 minutes, cool.

4. Add 20 mls of distilled water, bring to a boil, boil 5 minutes, cool.

5. Add 1 drop of phenolphthalein, neutralize with 10 NaOH to a faint pink color.

6. Just discharge pink color with 1NH_2SO_4, dilute to 100 ml, mix.

7. Place solution from step 6 in the sampling cup of the autoanalyzer.

8. Obtain the phosphorus concentration of the sample from the standard curve.

B. Total Soluble Phosphorus

1. Same as total phosphorus, except the aliquot is filtered through an Angel Reeves glass fiber pad 934AH.

C. Soluble Ortho-Phosphate

1. Filter through Angel Reeves glass fiber pad 934AH.

2. Dilute filtrate if needed.

3 Place in sampling cup of the autoanalyzer.

Reagents

A. Ammonium Molybdate - Dissolve 200 gm of $(NH_4)_6 Mo_7 O_{24} .4H_2O$ in 10 liters of distilled water. Add 1680 ml of conc. H_2SO_4 and dilute to 20 liters.

B. ANSA Stock Solution - Dissolve 219 gm $Na_2S_2O_5$ and 8 gm Na_2SO_3 in 700 ml of distilled water (temperature <50° C), add 4 gm of 1-amino- 2-naphthol -4- sulfonic acid. Dilute to 2 liters. For daily use, prepare a 1:10 dilution.

C. Phosphorus Standard Curve use standards, both digested and undigested from 0.1 to 1.2 mg/L-P in increments of 0.1 mg/L-P from a 1000 mg/L-P stock (4.386 gm of KH_2PO_4, oven dried at 103°C for 4 hours, in one liter).

D. Ternary Acid Mixture - Add 100 mls of 96% H_2SO_4 to 500 mls of 70% HNO_3, mix. Add 200 mls 70% $HClO_4$, mix and cool.

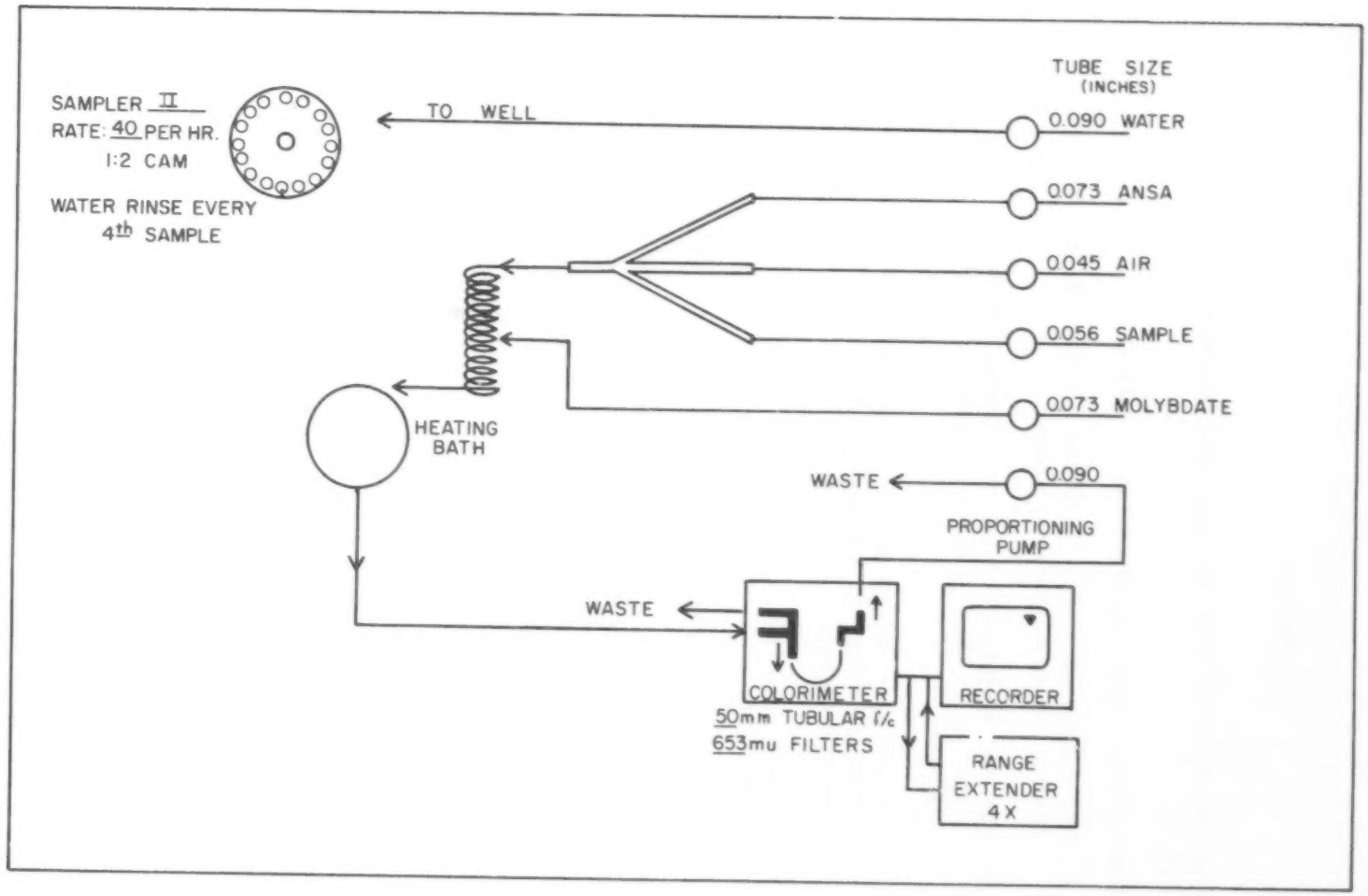

FIGURE 19 TECHNICON AUTOANALYZER SCHEMATIC

APPENDIX B

PROCEDURE USED FOR MLSS AND RSSS DETERMINATION:

A. Determination of SS concentration by weight.

1. Mix sample well, pour (100 mls for ML., 50 mls for RS) into a 100 ml graduate cylinder.

2. Add 5% chlorhydrol solution (6 drops for ML and 12 drops for RS) mix 3 times by inversion, let sit for 5 minutes.

3. Filter under vacuum thru tared filter paper (9cm, S and S Sharkskin for ML, Whatman No. 3 for RS) placed on a buechner funnel.

4. Dry the paper for 1 hour at 103° C in a Forced Draft Oven.

5. Cool it for 5 minutes in a dessicator and weigh back.

6. For MLSS subtract from this weight the tare weight of the paper. This gives solids in units of grams which in turn is equivalent to per cent by weight. (For RSSS since we used 50 ml sample, therefore multiply the above weight by a factor of two to get per cent RSSS by weight).

B. Determination of MLVSS

1. Place the filter paper with MLSS (use low ash S and S filter paper) after step 5 in a previously ashed and tared silica dish, and then ash for 15 minutes at 600°C.

2. Cool for 30 minutes in a dessicator and then weigh back.

3. The MLSS less the MLSS ash divided by the MLSS when multiplied by 100 equals per cent MLVSS.

APPENDIX C

BOD DETERMINATION

Dilution Water

1. Add 1 ml of the following solutions (33) to each liter of aged distilled water, 5 or more days.

   Phosphate Buffer Solution
   Magnesium Sulfate Solution
   Calcium Chloride Solution
   Ferric Chloride Solution

2. Aerate this mixture for 5 minutes.

Meter Setting

1. Place probe in aerating distilled water for 5 minutes.
2. Check zero and adjust if necessary.
3. Check red line and adjust if necessary.
4. Determine barometric pressure.
5. Read temperature on meter.
6. Determine DO setting with pressure-temperature chart.
7. Adjust calibration for DO of the day.

Procedure

1. Discharge stale water in buffer line.
2. Siphon dilution water into BOD bottle for blank.
3. Place probe in BOD bottle and read DO when meter stabilizes.
4. Stopper with rubber seal and incubate for 5 days, dilution water blank.
5. Determine dilutions to be made (set of 2) for samples.
6. Siphon dilution water to cylinder, filling to required mark.
7. Add sample desired with pipette or siphon.
8. Mix well with plunger and siphon to BOD bottles.
9. Determine DO, stopper and seal, and incubate 5 days.
10. After 5 days remove from incubation and determine DO as before.

Calculations

1. Initial DO - 5 day x dilution factor = 5 day BOD

2. Conversion factors of 4 and 6 day sewage and effluent BOD's to 5 day BOD, dividing by appropriate factor listed below.

	4 day	6 day
Sewage	.875	1.076
Effluent	.796	1.231

DILUTION TABLE

parts Sample		parts dilution H_2O	ml dilution H_2O	add ml of Sample
1	+	1	150 ml	150 ml
1	+	3	225 "	75 "
1	+	9	270 "	30 "
1	+	19	285 "	15 "
1	+	39	292.5 "	7.5 "
1	+	49	294 "	6 "
1	+	79	296.25 "	3.75 "
1	+	99	297 "	3 "

APPENDIX D

DISCUSSION OF MATERIAL FOUND FLOATING ON THE SURFACE OF THE EP AERATION TANKS AND THE AEROBIC DIGESTION OF WASTE SLUDGE.

The principal microorganism found in this material floating on the surface of the E.P. aeration tanks was identified as belonging to Actinomycetaceae and to the Genus Nocardia. A sample of this material was found to contain 85% volatile matter and 31% hexane soluble materials. Regular defoaming agents as mentioned before were ineffective in breaking this foam. Vacuum skimming of aeration tanks and clarifier feed channels reduced the amount of foam and aided in overcoming this problem. This floating material did not appear during all this time in the WP.

The effect of extended aeration on the stability of the Actinomycetaceae foam was also investigated. The East Plant Reserve Return Sludge channel was filled with approximately 286,000 gallons of waste sludge. This waste sludge was vigorously aerated for 21 days (3-25-69 to 4-15-69). The air application rate could not be defined because the air supply to this RS channel was not metered. At no time during this lengthy aeration period was a decrease in the quantity or the density of the Actinomycetaceae foam observed.

During this study it was also decided to observe the effect of extended aeration on the aerobic digestion of the waste sludge containing this floating matter. Seven liter composite samples were taken out of the aerated sludge for several days during this experiment and analyzed for TP,TSP, SOP, SS, VSS, pH and total Nitrogen. The results of these analyses are presented in Table 25. Some of the variation in the data was caused by sampling and analytical errors. Further, a part of the reduction of SS and TP in the aerated waste sludge was due to the dilution caused by some waste water entering the reserve RS channel.

The following general observations were made regarding the aerobic digestion of sludge in the reserve RS channel.

1. There appeared to be an acclimatization period of approximately 2 to 3 days before the aerobic digestion of the solids began.

2. After the acclimatization period, aerobic digestion of the sludge solids was significant as indicated by a sudden increase in the soluble phosphorus and a decrease in the %VSS and % nitrogen in the waste sludge solids.

TABLE 25

AEROBIC DIGESTION OF SLUDGE

Date	Day	*	Phosphorus mg/L-P			Sludge Solids		pH	%N in Sludge (Dry)	%P in Sludge (Dry)
			TP	TSP	SOP	MG/L	% VSS			
1969										
3-25	Tu	0	-	-	-	-	-	-	-	-
3-27	Th	2	280	2.4	2.1	10,000	64.5	7.1	6.64	2.78
3-28	F	3	270	3.4	2.8	9,430	63.8	7.3	-	2.83
3-31	M	6	266	-	14.6	8,340	56.6	7.2	6.70	3.13
4-2	W	8	246	25.4	14.7	7,890	59.3	7.0	-	2.80
4-3	Th	9	258	32.8	32.5	7,180	56.4	7.1	5.95	3.14
4-7	M	13	238	48.6	46.9	5,910	55.3	7.1	5.86	3.20
4-9	W	15	226	51.6	49.1	6,300	56.2	7.0	-	2.78
4-11	F	17	239	58.3	53.4	5,560	55.7	7.0	6.05	3.25
4-14	M	20	220	56.0	53.6	5,010	53.5	7.1	-	3.27
4-15	Tu	21	205	53.1	52.9	4,350	-	-	5.90	3.49

*Number of days aerated.

3. In a period of 6 to 8 days over 45% of the volatile matter in the waste sludge solids was reduced and after that the % reduction of volatile matter did not increase significantly.

4. During aerobic digestion of sludge solids, the solids appeared to hold the remaining phosphorus very strongly. This was shown by the increase in the % phosphorus in the solids on a dry basis as the digestion progressed.

5. Aerobic digestion of sludge solids had no effect on the pH value of the sludge.

It was observed that similar floating material started to reappear in November (1969) in small quantitites and on limited occasions in both plants when no changes in loading or other process parameters were made. This foam then continued to build up to the extent where it started affecting the operation of both the plants. The cause or causes of the appearance of this floating material and the controlling of this material by process parameters changes is not yet fully known but we did seem to have limited success in overcoming this floating material by increasing F/M loadings.

APPENDIX E

AVERAGE DAILY SCREENED SEWAGE CHARACTERISTICS AND PLANT OPERATION DATA

SCREENED SEWAGE CHARACTERISTICS		1967	1968	1969
Flow	mgd	183.4	183.4	181.6
BOD	mg/L	297	306	239
SS	mg/L	304	314	227
TP	mg/L	8.4	9.6	8.4
TSP	mg/L	---	---	3.5
SOP	mg/L	---	2.8	2.3
% of TP in SS		---	---	57.2

PLANT OPERATION		1967 WEST	1967 EAST	1968 WEST	1968 EAST	1969 WEST	1969 EAST
Flow	mgd	74.5	109.0	76.3	107.2	76.4	105.2
BOD	mg/L	15.1	18.2	26.8	19.2	21.3	14.8
SS	mg/L	22	25	47	30	41	23
TP	mg/L	1.2	1.3	2.2	1.7	2.0	1.4
TSP	mg/L	---	---	---	---	0.99	0.86
SOP	mg/L	---	---	0.87	0.83	0.86	0.73
DETENTION TIME UNDER AIR HOURS		6.8	6.6	6.8	6.8	6.6	6.8
Air Applied Cu. ft./gal. Sewage		1.40	1.22	1.37	1.21	1.36	1.20
Food/Microorganism Ratio		0.425	0.453	0.425	0.440	0.391	0.388
MLSS	MG/L	2800	2700	2900	2800	2600	2600
% RS		28.0	25.4	28.2	25.4	27.5	25.4
Lbs. BOD per 1000 cu. ft. of Aeration Tank Capacity		58.1	60.2	59.4	60.5	47.8	47.5

APPENDIX F

TOTAL PHOSPHORUS REMOVAL AT THE JONES ISLAND PLANTS BASED ON PLANT FLOWS

The values used in the calculations are yearly averages.

	1967	1968	1969	Grand Total
Influent				
Flow MGD	183.4	183.4	181.6	-
TP mg/L-P	8.4	9.6	8.4	-
TP pounds	12,848	14,684	12,722	40,254

	W	E	W	E	W	E	
Plant Effluent							
Flow MGD	74.5	109.0	76.0	107.2	76.4	105.2	-
TP mg/L-P	1.2	1.3	2.2	1.7	2.0	1.4	-
TP pounds	746	1182	1400	1520	1274	1228	-
Total TP pounds	1928		2920		2502		7350
% Removal	85.0		80.1		80.3		81.7

W = West Plant

E = East Plant

1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM
W	05	

5 Organization

Sewerage Commission of the City of Milwaukee,
Milwaukee, Wisconsin

6 Title

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27 Abstract

The overall total phosphorus removal in conventional activated sludge treatment plants at Jones Island, Milwaukee, Wisconsin, averages 80% as opposed to less than 50% in the majority of the activated sludge plants elsewhere in this country. A detailed plant-scale evaluation of the activated sludge process parameters was made over a period of three years to obtain optimum values for phosphorus removal. The total phosphorus removal generally followed the variations of the flow and BOD of the plant influent and was not dependent on the clarifier sludge blanket-depths. The BOD and the total phosphorus loading rate on the microorganisms and the MLSS concentrations were found to be of some significance in the removal of phosphorus. Total phosphorus removal was directly related to the solids (Milorganite) production. A significant portion of the phosphorus is insolubulized in the wastewater beforeit reaches the plant. It is proposed that this is a probable cause for the higher total phosphorus removals obtained. It appears that brewery waste water aids soluble phosphorus removal at the Milwaukee plants. Limited studies with waste pickle liquor addition to the ML indicated that consistently higher soluble phosphorus removals can be obtained without any apparent detrimental effect on the process or equipment.

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